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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER Miscellaneous Paper A-77-3	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER 9
4. TITLE (*and Subtitle*) 6 PROCEEDINGS, RESEARCH PLANNING CONFERENCE ON THE AQUATIC PLANT CONTROL PROGRAM, 19-22 OCTOBER 1976, Atlantic Beach, Florida.		5. TYPE OF REPORT & PERIOD COVERED Final report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) 14 WES-MP-A-77-3		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station Mobility and Environmental Systems Laboratory P. O. Box 631, Vicksburg, Mississippi 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 12 319 p.
11. CONTROLLING OFFICE NAME AND ADDRESS Office, Chief of Engineers, U. S. Army Washington, D. C. 20314	11	12. REPORT DATE August 1977
		13. NUMBER OF PAGES 322
14. MONITORING AGENCY NAME & ADDRESS(*if different from Controlling Office*)		15. SECURITY CLASS. (*of this report*) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (*of this Report*)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (*of the abstract entered in Block 20, if different from Report*)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (*Continue on reverse side if necessary and identify by block number*)

Aquatic plant control–Congresses
Research planning–Congresses

20. ABSTRACT (*Continue on reverse side if necessary and identify by block number*)

The 11th Annual Meeting on the U. S. Army Corps of Engineers Aquatic Plant Control Research Program was held in Atlantic Beach, Florida, on 19-22 October 1976 to review current operations activities and to afford an opportunity for presentation of current research projects.

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PREFACE

The 11th Annual Meeting on the U. S. Army Corps of Engineers Aquatic Plant Control Research Program was held at the Turtle Inn, Atlantic Beach, Florida, on 19-22 October 1976. The meeting was organized by personnel of the Aquatic Plant Research Branch (APRB), Environmental Systems Division (ESD), Mobility and Environmental Systems Laboratory (MESL), U. S. Army Engineer Waterways Experiment Station (WES).

The organizational activities were carried out and the presentations by WES personnel were prepared under the general supervision of Messrs. W. G. Shockley, Chief, MESL, and B. O. Benn, Chief, ESD, and under the direct supervision of Mr. J. L. Decell, Chief, APRB. Mr. W. N. Rushing, APRB, chaired the meeting and was responsible for assembling these proceedings.

This report was published with funds provided by the Directorate of Civil Works, Office of the Chief of Engineers, U. S. Army, Appropriation No. 96X3122, Construction General.

COL John L. Cannon, CE, was Commander and Director of the WES at the time of this meeting and during the preparation of the report. Mr. F. R. Brown was Technical Director.

b/all
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ATTENDEES

11th ANNUAL MEETING
U. S. ARMY CORPS OF ENGINEERS
AQUATIC PLANT CONTROL RESEARCH PROGRAM

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Atlantic Beach, Florida

19-22 October 1976

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AGENDA

11th ANNUAL MEETING
U. S. ARMY CORPS OF ENGINEERS
AQUATIC PLANT CONTROL RESEARCH PROGRAM

Turtle Inn
Atlantic Beach, Florida

19-22 October 1976

W. N. Rushing, Chairman

Tuesday, 19 October

1000-1800	Registration—Turtle Inn Lobby	

Wednesday, 20 October

0830	Call to Order and Introduction of Host District Engineer	W. N. Rushing
0835	Welcome	COL D. A. Wisdom
0850	Administrative Announcements and General Remarks	W. N. Rushing
0900	The Aquatic Plant Control Program Goals and Objectives	H. R. Hamilton
0930	Overview of the U. S. Army Corps of Engineers Aquatic Plant Control Research Program	J. L. Decell
0955	Status of EPA Regulations of Aquatic Herbicides	J. G. Cummings
1015	Coffee Break	
1035-1200	Corps of Engineers Division and District Representatives Reports	
	Canal Zone Problems*	LTC P. E. Custer
	Current Status of the Aquatic Plant Control Program in Texas	W. T. Nailon
	Status of Reconnaissance Survey Report and Review of Aquatic Plant Problems in the State of Oklahoma	L. M. Mason
	East Texas Reservoirs—Aquatic Plant Control	E. J. Moyer
	Aquatic Plant Control Program in the St. Paul District	D. E. Wadleigh

* Not included herein.

	Aquatic Plant Control Activities—Ohio River Division	C. W. Crews
	Aquatic Plants—South Atlantic Division	J. J. Raynes
1200	Lunch	
1335-1500	Corps of Engineers Representatives Reports (Continued)	
	Aquatic Plant Control Program—Mobile District	M. J. Eubanks
	Aquatic Plant Problems—Lake Seminole—U. S. Army Corps of Engineers	A. K. Gholson, Jr.
	Selective Maintenance Control Plan—St. Johns River, Florida	J. C. Joyce
	Résumé—Aquatic Plant Control Program—Wilmington District	O. H. Johnson, Jr.
	Aquatic Plant Control in the Savannah District	K. Williams
	Aquatic Plant Control in the Charleston District*	J. L. Carothers
1500	Coffee Break	
1520-1635	Corps of Engineers Representatives Reports (Continued)	
	Control of Water Chestnut in New York State	S. M. Hook
	Status of the Aquatic Plant Control Program in the Norfolk District, Norfolk, Virginia	J. D. Haluska
	Automated Processing of APC Field Operations Data	J. T. McGehee
1635	Summation of the Day's Discussions	B. O. Benn

Thursday, 21 October

0830	Call to Order and Announcements	W. N. Rushing
0840	The Projected Impact of Waterhyacinth Infestation in Texas	A. R. Benton, Jr.
0910	The Large-Scale Operations Management Test (LSOMT) with the White Amur at Lake Conway, Orlando, Florida	R. F. Theriot
0925-1015	Reports of LSOMT Contractors (R. F. Theriot, Chairman)	
	Baseline Data Report—Lake Conway Grass Carp Project	V. Guillory
	Aquatic Macrophyte Sampling in Lake Conway	L. E. Nall
	Biological Baseline Studies of the Lake Conway, Florida, System	J. L. Fox

* Included herein although not presented at the meeting.

1015	Coffee Break	
1035-1135	Reports of LSOMT Contractors (Continued)	
	Background Water Quality-Analysis of Lake Conway	A. T. Sawicki
	Proposed Relationships Between White Amur and the Aquatic Ecosystem at Lake Conway, Florida	K. C. Ewel
	Culture Techniques for the Production of Monosex White Amur	A. E. Thomas
1135	Reports of Chemical Research Contractors	
	Response of Hydrilla to Various Herbicides	L. V. Guerra
1200	Lunch	
1300	Field Trip to Orange Lake, Marjorie Rawlings State Park	

Friday, 22 October

0830	Call to Order and Announcements	W. N. Rushing
0835-0950	Reports of Chemical Research Contractors (Continued)	
	Uptake and Metabolism of Dimethylamine Salt of 2,4-D by Fish	H. C. Sikka*
	Characterization and Evaluation of Polymers Containing Herbicides as Pendent Side Chains	F. W. Harris
	Development and Evaluation of Controlled Release Herbicides	G. A. Janes
	Efficacy Evaluation of Controlled-Release Herbicides	J. R. Barry
0950	Reports of Biological Research Contractors	
	Biological Control of Aquatic Plants with Insects**	N. R. Spencer
1015	Coffee Break	
1035	Reports of Biological Research Contractors (Continued)	
	Progress in the Use of Plant Pathogens as Biological Controls for Aquatic Weeds	R. Charudattan
1055	Report of Mechanical Research Contractor	
	Evaluation of the Aqua-Trio System for Harvesting Aquatic Plants in Florida**	C. B. Bryant

* Author was unable to attend; paper was presented by E. Pack.
** Not included herein.

1115	Report of Integrated Research Contractor	
	Preliminary Results of Integrating Chemical and Biological Controls to Combat Waterhyacinths	B. D. Perkins
1200	Lunch	
1330-1500	In-House Research Reports	
	Controlled Field Tests of Selected Insects and Pathogens in Combination on Waterhyacinth	E. E. Addor
	Remote Sensing of Aquatic Plants	L. E. Link, Jr.
	Data Management Systems in the Aquatic Plant Control Research Program	J. A. Parks
1500	Summary Comments	W. G. Shockley
1530	Adjournment	

11th ANNUAL MEETING
U. S. ARMY CORPS OF ENGINEERS
AQUATIC PLANT CONTROL
RESEARCH PROGRAM

INTRODUCTION

The Environmental Systems Division, Mobility and Environmental Systems Laboratory, U. S. Army Engineer Waterways Experiment Station, arranged for the 11th Annual Meeting on the U. S. Army Corps of Engineers Aquatic Plant Control Research Program to review current operations activities and to afford an opportunity for presentation of current research projects. The conference was held at the Turtle Inn, Atlantic Beach, Florida, 19-22 October 1976. A list of attendees is given on pages ix-xvi. The conference agenda is presented on pages xvii-xx. The papers presented at the meeting are published in full herein, except as noted on the agenda.

OPENING REMARKS TO THE AQUATIC PLANT CONTROL RESEARCH PROGRAM

by

COL D. A. Wisdom*

Good morning, Ladies and Gentlemen. Welcome to the Jacksonville District and the Corps' 11th Annual Aquatic Plant Control Research Meeting.

I see that we have a very diverse group of representatives here today. Of course, the Corps is well represented, but I also recognize individuals from other Federal agencies, state agencies, local governments, environmental groups, and interested individuals. I am certain that with a gathering of such an astute and diverse group, we can surely formulate ideas and plans for a truly meaningful and responsive research and control program.

I believe it is significant that this year's meeting is being held in Florida. From what I have seen, Florida is the leader in aquatic weed problems. Florida has all of the introduced species of aquatic weeds and experiences varying degrees of problems with all of them. Due to the favorable climate, the state was also unfortunate enough in most cases to be the first area to have them. Uncontrolled, these plants, waterhyacinth and hydrilla in particular, reproduce explosively and cause a myriad of problems for man and our environment. Having been exposed to the waterhyacinth the longest, we have been able to develop a limited amount of control, through the judicious use of 2,4-D in a selective maintenance control program. However, we are still not satisfied with this one method of control. As with any method of control, it has its drawbacks; thus, the Corps is looking at alternate or supplementary methods. For example:

1. After many years of the Corps' and other's research, the waterhyacinth weevil is available on a limited operational basis. The Jacksonville District collected, transported, and released approximately 24,000 weevils at 51 sites along the St. Johns River this year. Sites were selected that were not generally accessible to regular chemical treatment. The weevils are expected to expand in numbers and reduce the amount of plants that wash out of these inaccessible areas during high-water periods. Additional releases in other areas of waterhyacinth problems are planned for the future.

2. To more thoroughly understand another alternative, the Jacksonville District has sponsored a mechanical harvesting research effort by the Corps' Waterways Experiment Station. This is a 2-phase approach. Plan 1, or the first phase, is to collect available data on harvesting systems, test off-the-shelf equipment, and evaluate these data. Initially, the field test was to be in the St. Johns River on waterhyacinths only; however, the rapidly growing problem with hydrilla prompted us to include the testing of machinery on this plant also. The machinery was evaluated on hydrilla in Orange Lake, a still-water environment, and the Withlacoochee River where it was tested on waterhyacinths and hydrilla in a moving water or river situation. Plan 2 of the mechanical harvesting effort will draw together previous research and field data for the design of efficient harvesting systems that are capable of working for sustained periods under natural environmental conditions.

3. The Corps is also sponsoring a detailed study administered by the Waterways Experiment Station into the use of the weed-eating white amur fish for hydrilla control at Lake Conway near Orlando, Florida. This study effort should answer many questions on the fish's ability to control hydrilla

* District Engineer, U. S. Army Engineer District, Jacksonville, Florida.

and what effect the introduction of the fish will have on natural water bodies.

The Jacksonville District and others are progressively pursuing the integrated Aquatic Plant Control Program that is most responsive to our waterway users' needs and least environmentally disruptive. This approach will draw on all methods of control and use each, or a combination of each, where they are best suited. For the present, however, we must rely on the use of chemicals and the waterhyacinth weevil. Integration of other biological and mechanical control methods appears to be just around the corner.

In closing, I would like to note that I have experienced an encouraging trend in aquatic plant control research. The whole research program is becoming oriented to operational needs. Additionally, researchers, plant management people, and the public are communicating freely. Everyone recognizes that, at present, we do not have the ultimate answer to aquatic weed problems. However, a continuation of the free exchange of ideas will surely result in an integrated aquatic plant management program that is environmentally acceptable and responsive to the needs of the public.

THE AQUATIC PLANT CONTROL PROGRAM GOALS AND OBJECTIVES

by

H. Roger Hamilton*

The Aquatic Plant Control Program of the Corps of Engineers is authorized by Section 302 of the Rivers and Harbors Act of 1965, Public Law 89-298, which states in part:

> There is hereby authorized a comprehensive program for control and progressive eradication of waterhyacinth, alligatorweed, Eurasian watermilfoil, and other obnoxious aquatic plant growths from the navigable waters, tributary streams, connecting channels, and other allied waters of the United States, in the combined interest of navigation, flood control, drainage, agriculture, fish and wildlife conservation, public health, and related purposes, including continued research for development of the most effective and economic control measures, to be administered by the Chief of Engineers, under the direction of the Secretary of the Army, in cooperation with other Federal and State agencies.

Problems with aquatic plant growths exist in most parts of the country in varying degrees; however, our major problems occur in southern latitudes where subtropical and near subtropical climatic conditions provide long growing seasons and favorable habitat for vegetation.

The major problems exist with those species of aquatic plants that are not native to the United States. These species often do not present a problem in their native countries because of the presence of natural enemies or other limiting factors that keep populations in check. Transported to this country, the plants have found ideal growing conditions and a lack of natural enemies or other limiting factors that would result in population control.

A year ago last spring, responsibility for management of the Aquatic Plant Control Program was assigned to the Recreation-Resource Management Branch in the Office of the Chief of Engineers, with the directive to raise the level of performance of the program. During the past year and a half, considerable time and effort have been devoted to upgrading the effectiveness of the operational and research objectives.

Responsibility for research efforts in the control of aquatic plants has been assigned to the U. S. Army Engineer Waterways Experiment Station (WES) at Vicksburg, Mississippi. The WES is your host at this conference, and Mr. Lewis Decell, Chief of the Aquatic Plant Research Branch, and his staff will be here throughout the conference. I am sure they will be available for any discussions that you may want to have with them.

When we received the responsibility for management of the program and the orders to become operational fairly quickly, we established some goals and objectives under which we would operate. We have completely redirected the program. Our overriding goal is to provide tools, as the result of our research efforts, for those individuals in our operating districts as well as for our colleagues at state and local levels as soon as possible. Our research efforts are directed toward producing these tools in as short a time frame as is possible or practicable. The tools are then given, through the process we call technology transfer, to the operational elements. Toward the end of accomplishing this goal, we have

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* Biologist, Recreation-Resource Management Branch, Construction-Operations Division, Office, Chief of Engineers, Washington, D. C.

established a system of priorities under which we fund the program, and under which actions are initiated and carried out to completion.

That priority system is as follows: Our No. 1 priority is technology transfer, and this is accomplished in several ways that I will discuss later. Our second priority is research, and we break it down into two categories: Priority 2.a.—short-term research, and Priority 2.b.—long-term research.

Third in the list of major priorities of the program is our cost-sharing program for operational control of aquatic plants. This cost-sharing program falls under the authority of Section 302 of the 1965 Rivers and Harbors Act and provides for a 70-30 split in the operational control, with the Federal government providing 70 percent of the cost and state government providing 30 percent.

Fourth in our priority system is the planning effort, which must be carried out by the districts in order to implement an aquatic plant control program. This planning effort includes preparation of Design Memoranda for the control program and an Environmental Impact Statement under authority of Section 102 of the National Environmental Policy Act of 1969, Public Law 91-190.

This priority system is consistent with the goal of providing tools for the operations personnel as soon as possible. In view of the limited funding for the program, our planning effort must receive the lowest priority so that we may concentrate on ongoing projects before we begin new work.

At this point I'd like to go back to the technology transfer phase of the program implementation that we have established as No. 1 priority in the system. Technology transfer is simply the conveying of the results or conclusions derived from research to the user. It requires coordination and cooperation on the part of both the researcher and of the user. To put it in simple terms, the researcher throws the ball, the user catches the ball and runs for the touchdown. Without this team effort, we cannot succeed.

Accomplishment of the technology transfer phase is handled in a number of ways. The most common way of transferring technology from the researcher to the operator is through the use of a manual that spells out the conclusions and results of the research effort and outlines a procedure by which they may be implemented. For this to be successful, the researcher and operator must speak the same language. Too often, research reports come out with pages of formulae and scientific or technological language, which the operator in the field with mud on this boots and his background of practical experience cannot understand. This has been a hazard to the scientific community since time began.

However, there is a need for the technological language in our report system in the scenario of communicating with other individuals of equal skills. So, we are looking at two types of reports. One type of report or manual is aimed at the researcher's colleague engaged in the same or a similar endeavor, at the same level. The other type is addressed to the user who has a different level of appreciation, but he is the man that makes the program work. Communication is the key.

Training schools for specific control processes may also become necessary as a technology transfer method.

One phase of technology transfer that we have been employing in the Aquatic Plant Control Program is that of large-scale operations management tests. This is a rather long name for a rather involved process that employs researchers and operations people in a team effort. The objective, as can be ascertained from the name, is to test out those results of basic research that seem to be on the threshold of success as an operational tool and to refine the procedures for incorporation into field manuals. We feel that early involvement of state and local agencies, universities, organizations, and other interested parties during the conduct of these tests is essential. Their cooperation throughout the field test is most helpful.

When we were assigned the Aquatic Plant Control Program, our first decision was to drop the losers and go with the winners. We contacted personnel of the WES as well as those in the South Atlantic Division and the Jacksonville District, where the majority of our aquatic plant problems occur, to assess the state of the art in all phases of the control program, including biological, mechanical, chemical, water-level manipulation, and integrated processes.

One item that appeared to be near the threshold of success was a very controversial fish called the white amur, or grass carp. I am sure that you are all familiar with the fame and infamy of this biological control agent.

The fish will eat weeds. We know that. We do not know, nor does anyone know, what impact the fish has on the aquatic ecosystem into which it is introduced. The scientific community and also the sport fishermen continue to ask basic questions relative to the introduction of the fish into a natural system in a real world situation. For example: What effects does the fish have on the habitat of game fish species? What is its impact on benthic organisms; on water chemistry; on other aquatic plants; on waterfowl; on reptiles? In short, what happens to the aquatic ecosystem when white amur is introduced? We do not know. At Lake Conway on the south side of Orlando, Florida, we are currently collecting baseline data and expect to introduce the fish next spring in a long-term effort to find out what are the impacts of this fish in the aquatic ecosystem and what are the efficiency rates of this fish as a biological control agent on a large scale, in this case, an 1800-acre lake.

This project is being run by the WES and the Jacksonville District in cooperation with state and local agencies in Florida. The knowledge and skills of both sets of expertise, research and operations, are employed in this team effort. Whether we discover the white amur can be an effective tool that does not deter aquatic ecosystem processes, or one that significantly upsets the balance of the ecosystem, we think the technology transfer process and the cooperative effort of the team members will be successful. Hopefully, a new tool for aquatic plant control will be developed. However, if the project produces results that indicate severe deleterious impacts on the ecosystem by the white amur, we are prepared to abort the project. When dealing with biological control agents, we must have an "off-switch" built into the project.

This important interface between the research element and the operations element toward the solution of a problem is what technology transfer is all about.

The new direction of the Aquatic Plant Control Program requires the application of management skills at all levels, by all people involved in the program. This process has begun and some very hard questions are being asked. If the program is to succeed, these questions need accurate answers. Each of us must know where we are, where we are going, and how and when we are going to get there. We must understand the economic, biological, and fiscal implications of the actions we take.

One of the problems that we face in this program is a description or an assessment of the magnitude of the obnoxious aquatic plant problems. Especially throughout the southeastern United States, and in most of our other district offices, we have personnel responsible for the control of obnoxious aquatic plants. Most of you are here. How many of you can tell me what the magnitude of your problem is?

How many of you can tell me the economic impact of aquatic plants in your particular geographical jurisdiction on navigation, on flood control, on water supply, on fish and wildlife habitat, on recreation, on water quality, etc., etc., etc.?

How many of you can tell me what your 5-year program is for the control of aquatic plants? What are the priorities? What areas should you hit first? How much will it cost? How much cooperation from the states can you expect? What will be required in the way of registration of chemicals?

How many of you can tell me what your budgetary requirements are now, next year, and 5 years from now?

How many of you can tell me what the priorities of the control program should be? Where are the greatest infestations? Where do the efforts need to be directed?

How many of you can tell me what tools that you now use are effective and what your requirements are in the way of new tools?

This last question is extremely important. It is the reason we are here today. The operations man in the district has a problem with the control of obnoxious aquatic plants. Traditional methods, such as spraying, in many cases are what he relies on. There may be another method that can save him money, that would permit the diversion of manpower and funds to another important function of the Corps, and that could reduce the mass of plant control to a manageable level and maintain it at that level. Maybe that solution isn't too far around the corner.

It is the responsibility of the research people at the WES to help us find these answers. It is the responsibility of the operations people to identify the problems and ask for and actively seek solutions. I implore the operations people to put the pressure on the WES for answers. Likewise, I implore the research people at the WES to put the pressure on the operations people to help them with the solutions and to make them work. I think this team effort is extremely important in the solving of any problem that we may come across in our endeavors. I think it's especially important in this particular field of control of aquatic plants where so little data are available, especially meaningful data that we can rely on.

We are in a sense pioneering and breaking new ground here. For example, in the area of mechanical harvesters for food and fiber crops, the agricultural people have been working for centuries and now, in a terrestrial environment, are able to design harvesters, tractors, trucks, and combines for specific crops. They know how far apart the crops are planted, they know the densities, and so forth. We don't have that type of data in aquatic environments. Aquatic plants do not always fit the nice configuration of, for example, a cornfield. We need to find out what we are dealing with. We need to establish the characteristics of the plant infestations in terms useful for expressing work measurements requirements. We need the operators and the researchers to work together.

Some of the questions that I have raised in the last few minutes are very basic. They are questions that the manager of such a program should immediately address. The answers should be readily available. However, I am finding, much to my dismay, that we do not know the answers. Let us find out.

I'll be here through the remainder of the conference. We have the operations personnel and the researchers here in this room. I am looking forward to a good interchange of ideas; I think this is the proper forum for the beginning of a successful program.

OVERVIEW OF THE U. S. ARMY CORPS OF ENGINEERS AQUATIC PLANT CONTROL RESEARCH PROGRAM

by

J. L. Decell*

BACKGROUND

The U. S. Army Corps of Engineers is responsible for control of aquatic "weed" infestations of major economic significance, in addition to those that have potential to reach problem proportions in navigable waters, tributaries, streams, connecting channels, and allied waters. This responsibility is carried out operationally by the various districts of the Corps. The research program is being conducted to provide the technology needed to control or manage aquatic plant infestations in an environmentally compatible manner, at the least possible cost.

In early 1975, the Office of the Chief of Engineers assigned the Aquatic Plant Control Research Program to the U. S. Army Engineer Waterways Experiment Station (WES) with the directive to make the program more responsive to the operational requirements of the districts. For this reason, an important facet of the program is emphasis on the transfer of technology from the Corps' researchers to their operations counterparts in the districts. Also, the program emphasizes not only the identification or development of new control agents, but also the necessary methods and techniques for their proper use on a continuing operational scale.

By the beginning of the past year, the objectives of ongoing and new research were focused more clearly on operational problems found nationwide. When one considers the number and diversity of the problem weed species, environments where these problem weeds occur, the uses of land adjacent to the weed control operations, and political aspects of the various Federal, State, and local weed control programs, it is obvious that no single control technique will be adequate. Yet, because the management of aquatic plants must be relatively inexpensive, the comprehensive solution sought requires the use of systems analysis techniques that permit study of the effectiveness of various control agents used singly or in combinations.

For management purposes, the research effort is separated into elements that include identification, assessment, and classification; development of mechanical, biological, chemical, and integrated control technology; development and optimization of application methods; *development of management capabilities;* and transfer of technology.

The WES has established as an objective of each program element the publication of a manual that will:

a. Allow the Corps operational field units to better assess and classify the type of aquatic plant problems they face.

b. Provide a technique for rationally selecting the type and method of control that can be applied for each problem class.

c. Give guidance as to the degree of control that can be expected from each control technique applied in a given problem class.

Preparation of these manuals will require the ability to predict the effectiveness of various control

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agents applied under a variety of conditions. Also, in compliance with existing laws, such preparation requires the ability to predict any subsequent environmental effects resulting from weed control operations and means of mitigating them.

The elements of the research effort are discussed in more detail in the remainder of this paper.

PROBLEM IDENTIFICATION, ASSESSMENT, AND CLASSIFICATION

This element involves development of techniques for locating, identifying, assessing, classifying, and monitoring problem aquatic plant populations.

The water-covered surfaces in the United States comprise slightly over 2 percent of the total surface area. This vast water-covered area of over 42,763,950 hectares (427,281 km^2) is the potential habitat (depending on the suitability of growing conditions in a specific locality) for at least 50 noxious aquatic plants (Table 1), which have created problems of various degrees depending on the type and intensity of water use.

Presently, the most prevalent problem species occurring in high-use areas are four: waterhyacinth (Eichhornia crassipes (Mart.) Solms), alligatorweed (Alternanthera philoxeroides (Mart.) Griesb.), hydrilla (*Hydrilla verticillata* Royle), and waterlettuce (*Pistia stratioties* L.). In addition to these four, three other species have presented continuing problems: Eurasian watermilfoil (*Myriophyllum spicatum* L.), Brazilian elodea (*Egeria densa* Planch.), and waterchestnut (*Trapa natans* L.). These seven species are emphasized in the research program.

Remote sensing studies are being conducted to establish the optimum film-filter combinations and other mission parameters, i.e. proper time of day to fly the air-photo mission, flight altitudes, etc., that must be used if a target species is to be identified. Also, work has been initiated on the development of a system that will permit classification of various aquatic plant infestations such that an adequate control method can be more readily tailored to a specific problem.

DEVELOPMENT OF CONTROL TECHNOLOGY

Mechanical Harvesting

Mechanical harvesting of aquatic plants is being evaluated comprehensively, i.e., equipment, locations, plant types, disposal methods, cost, environmental impact, and reasons for minimal success over the years are being studied. The results of this study will be used to assess present mechanical control technology from a systems analysis perspective and to help identify aspects of this technology that can be improved. It is expected that this approach will lead ultimately to a capability for determining the most cost-effective mix of machines and operations techniques for controlling aquatic plants in various environments. At present, field tests are being conducted in Florida with machines being used under contract with the Aquamarine Corporation, Waukesha, Wisconsin. Also, other concepts that make more effective use of natural forces, such as wind and water current, are being studied. The most promising will probably be selected for field testing in Florida early in 1977.

Biological Control

In the WES research on biological control methods, various species of insects, plant pathogens, and fish have been and are being evaluated in the laboratory and in both large- and small-scale field tests.

Table 1

Aquatic Plant Research Program Target Species

Common Name	Botanical Name
	Algae
Anabaena	*Anabaena* spp.
Chara	*Chara* spp.
Cladophora	*Cladophora* spp.
Hydrodictyon	*Hydrodictyon* spp.
Microcystis	*Microcystis* spp.
Nitella	*Nitella* spp.
Oedogonium	*Oedogonium* spp.
Pithophora	*Phithophora* spp.
Spirogyra	*Spirogyra* spp.
	Emergent Plants
Alligatorweed	*Alternanthera philoxeroides* (Mart.) Griseb.
American lotus	*Nelumbo lutea* (Willd.) Pers.
Arrowhead	*Sagittaria* spp.
Cattail	*Typha* spp.
Fragrant waterlily	*Nymphaea odorata* Ait.
Frogbit	*Limnobium spongia* (Bosc.) Steud.
Pickerelweed	*Pontederia* spp.
Slender spikerush	*Eleocharis asicularis* R. and S.
Smartweed	*Polygonum* spp.
Spatterdock	*Nuphar advena* (Ait.) Ait. F.
Water pennywort	*Hydrocotyle* spp.
Watershield	*Brasenia schieberi* Gnelin
	Aquatic Grasses
Cutgrass	*Leersia hexandra* (Swoatz.)
Giant foxtail	*Setaria magna* Brisb.
Giant reed	*Phragmites communis* (Trin.) Rud.
Maidencane	*Panicum hemitomom* Schult.
Paragrass	*Panicum purpurascens* Raddi.
Sawgrass	*Cladium jamaicensis* Grantz.
Southern watergrass	*Hydrochloa carolinensis* Beauv.
Torpedograss	*Pancicum repens* L.
Water paspalum	*Paspalum fluitans* (Ell.) Kunth.
	Floating Plants
Common duckweed	*Lemna minor* L.
Giant duckweed	*Spirodela* spp.
Floating waterhyacinth	*Eichhornia crassipes* (Mart.) Solms-Lauback
Salvinia	*Salvinia* spp.
Waterfern	*Azolla* spp.
Waterlettuce	*Pistia stratioties* L.
Watermeal	*Wolffia* spp.
Wolffiella	*Wolffiella* spp.

(Continued)

Table 1 (Concluded)

Common Name	Botanical Name
	Submersed Plants
Brazilian elodea	*Egeria densa* Planchon
Common bladderwort	*Uticularia* spp.
Coontail	*Ceratophyllum demersum* L.
Eelgrass—Tapegrass	*Vallisneria* spp.
Eurasian watermilfoil	*Myriophyllum spicatum* L.
Fanwort	*Cabomba caroliniana* L.
Hydrilla	*Hydrilla verticillata* Royle
Illinois pondweed	*Potomogeton illinoensis* Morong
Marine naiad	*Najas marina* L.
Parrotfeather	*Myriophyllum brasiliense* Camb.
Southern naiad	*Najas guadalupensis* (Spring.) Morong
Widgeongrass	*Ruppia marithima* L.

This program will be accelerated, with increased emphasis on the search for additional biological control agents and investigation of their limits of environmental adaptability. Some of the more important studies are discussed below.

Field test of the white amur. A large-scale test for introducing the white amur (*Ctenophoryngoden idella*, Val.) fish into a field environment is being initiated at Lake Conway near Orlando, Florida, to study the effectiveness of this fish in controlling hydrilla. Its introduction in most cases has been carefully controlled, and it has been outlawed in several states. Other states allow its introduction under stringent controls for experimental purposes.

Through research sponsored by the U. S. Army Corps of Engineers, personnel at the U. S. Department of the Interior Fish Farming Experiment Station at Stuttgart, Arkansas, have developed a white amur reproductive technique that results in all female (monosex population) offspring, so that a nonreproductive population can be introduced into a test area. Hybridization experiments have demonstrated that these monosex genotypes are not able to hybridize with the other naturalized carp species. Thus, the population of the white amur in a test area can be specified and controlled at the time of and subsequent to introduction. It appears, therefore, that the monosex white amur has good potential as a plant control agent.

Insects and pathogens. Work with insects and pathogens is being carried on in cooperation with the U. S. Department of Agriculture (USDA) Biological Control Laboratory and the University of Florida Plant Pathology Department, respectively, both at Gainesville, Florida. Alligatorweed has been successfully controlled in the southern part of the United States with the flea bettle (*Agasicles hygrophila*). Recently, emphasis has been placed on biological control of waterhyacinths by using endemic pathogens of waterhyacinth—*Acremonium zonatum, Cercospora piaropi, C. rodmanii, Rhizoctonia solani*—and three exotic ones—*Bipolaris stenospilla, Uredo eichhorniae*, and *Rhizoctonia* sp. The University of Florida has carried out extensive cultural studies in the laboratory; greenhouse studies, including cross-inoculation of other plant species; host range studies; and, in the case of the endemic pathogens, small-scale field tests. These latter tests have shown that *A. zonatum* and *C. rodmanii* have considerable potential as biocontrols. The WES is presently testing both of these combined with two insects (*Neochetina eichhorniae* and *Arzama densa*), in Lake Concordia, Louisiana.

The preliminary results of these tests indicate that the combination of an insect and a pathogen are considerably more effective than one agent alone. In fiscal year 1977 (1 October 1976-30 September 1977), the USDA Biological Control Laboratory, under contract to the WES, will attempt to find and perform preliminary evaluations of insect enemies of two plant species, *Myriophyllum spicatum* and *Hydrilla verticillata*. The field work will be done in Europe and Africa for the two target species, respectively. Also, the USDA laboratory will attempt to determine, by tests conducted under quarantine, the suitability of selected insect species for potential use in the United States as biological agents for control of aquatic weeds. The agents under test will include, but will not necessarily be restricted to, *Sameodes albiquittalis* (as an agent against waterhyacinth) and *Paraponyx stratiotata* (as an agent against Eurasian watermilfoil).

Chemical Control

Chemical compounds per se and techniques and equipment for their application are being tested and evaluated in cooperation with Wright State University, Dayton, Ohio; University of Southwestern Louisiana, Lafayette, Louisiana; Syracuse Research Corporation, Syracuse, New York; and Creative Biology Laboratory, Barberton, Ohio. Special emphasis is being placed on the research required for Federal registration of chemicals for aquatic use. Other studies, such as the effectiveness of slow-release herbicides, are in progress; and testing of the Marsh Screw amphibious vehicle as a spray platform has recently been completed and documented. The following paragraphs touch on specific ongoing work.

Slow-release herbicides. A series of vinyl monomers containing 2,4-dichlorophenoacetic acid (2,4-D) or 2- (2,4,5-trichlorophenoxy) propionic acid (Silvex) has been synthesized. The monomers were polymerized by bulk-, solution-, and emulsion-free-radical techniques to yield various compounds. Work is under way to determine the effects of pH and water temperature on the release rate of the most promising polymers, the synthesis and polymerization of a new series of vinyl monomers containing Fenac, and the determination of the release rates of the polymers containing Fenac. Test quantities (500-2000 g) of those polymers containing herbicides selected for initial laboratory bioassay will be synthesized, and the activity of these polymers will then be determined by bioassay with several aquatic weeds. A method for treating submersed aquatic weeds with polymers containing herbicides is also being developed.

In addition to the work described above, Diquat, 2,4-D acid, and Silvex have been embedded in various concentrations in hot polymerized styrene-butadiene copolymer, cold polymerized styrenebutadiene copolymer, natural rubber, synthetic rubber, cis polybutadiene, and an ethylene-propylene-diene terpolymer. In addition, Fenac acid, Fenuron, and Endothall compounds that could be processed were prepared in the same matrices. Loss rate for these matrices is being analyzed, and efficacy studies are being conducted to determine acceptable dosages of controlled-release herbicides for various plant species.

Also, small-scale field studies are being conducted with the most promising slow-release materials on waterhyacinth, Eurasian watermilfoil, Egeria, and other aquatic species.

Fate of herbicides. Considerable work on the fate of herbicide compounds and their metabolism has been done. Recent work has included determination of (a) 2,4-D residues in blue crabs collected from the St. Johns River in Florida, (b) uptake of 2,4,7,8-tetrachlorodibenzo-p-dioxin (TCDD) by selected species of algae, and (c) metabolism of chlorodioxin by microorganisms.

Integrated Control

The biological control work discussed earlier has shown that some agents used in combination on a

given problem plant have a greater effect than the same agents used individually, i.e., the control effect is synergetic rather than additive in many cases. Agents to be studied in the future in integrated applications include selected combinations of environmental manipulation and mechanical, biological, and chemical agents. Various combinations of chemical and biological agents are presently being planned for field investigation at Lake Concordia, Louisiana.

DEVELOPMENT AND OPTIMIZATION OF APPLICATION METHODS

Application of control technology in an optimal manner requires a quantitative understanding of the aquatic ecosystem and its response to the various control agents, and a knowledge of the operations limitations of the equipment required to apply the control agent. Simulation models of the aquatic ecosystem and the operations conducted therein are under development in cooperation with the University of Florida, Gainesville, Florida. Aquatic plant control methods will be optimized through the use of the developed models. The model studies will be validated with field exercises.

DEVELOPMENT OF MANAGEMENT CAPABILITY

Pursuant to a continuing need for communicating ideas and principles that can be used to develop long-term aquatic plant management plans, a concept has been formulated that provides for consideration of those factors critical to objective aquatic plant management for a lake or river ecosystem. Emphasis in this concept is placed on the determination of control agent(s) to be used and their impact on the target plant species, system user demands, limiting environmental conditions, and potential environmental modification by control agent(s). This management concept is composed of five parts, reflecting the fact that successful implementation of a management plan for aquatic plants occurs in five distinct phases. These are:

a. Phase I: Problem Identification and System Description.

b. Phase II: Problem Scoping.

c. Phase III: Selection of Control Techniques.

d. Phase IV: Operational Plan Development.

e. Phase V: Operational Plan Implementation and Monitoring.

During fiscal year 1977, this concept will be applied to aquatic plant problems in reservoirs under management by the Tulsa, Mobile, Ft. Worth, and Galveston Districts and Gatun Lake of the Panama Canal.

TRANSFER OF TECHNOLOGY

As emphasized earlier, transfer of technology is being emphasized in the Corps Aquatic Plant Control Research Program. Three means are being used to enhance the flow of information from the researchers to private, State, and Federal agencies and to the Corps districts; namely, a public information program for the Aquatic Plant Control Research Program, technical reports on various studies conducted under the Aquatic Plant Control Research Program (Table 2), and large-scale operations management tests.

Table 2
Technical Reports Prepared in the Aquatic Plant Control Research Program

Published

Report 1.	Controlled Release Herbicides
Report 2.	Response of Aquatic Weeds to Laser Radiation
Report 3.	Biological Control of Alligator Weed
Report 4.	Herbivorous Fish for Aquatic Plant Control
Report 5.	Aquatic Use Pattern for Silvex
Report 6.	Biological Control of Waterhyacinth with Insect Enemies
Report 7.	Aquatic Use Patterns for 2,4-D Dimethylamine and Integrated Control
Report 8.	Aquatic Weed Control with Plant Pathogens
Report 9.	Integrated Control of Alligator Weed and Waterhyacinth in Texas
Report 10.	Integrated Control of Alligator Weed and Waterhyacinth in Texas
Report 11.	Effects of CO_2 Laser on Waterhyacinth Growth
Report 12.	Butoxyethanol Ester of 2,4-D for Control of Eurasian Water Milfoil
Report 13.	Diquat for Control of Egeria and Hydrilla
Proceedings, Research Planning Conference on Integrated Sytems of Aquatic Plant Control, 29-30 October 1973	
Proceedings, Research Planning Conference on Aquatic Plant Control Project, 12 January 1972	
Proceedings, Research Planning Conference, October 1975	
Test Plan for the Large-Scale Operations Management Test of the Use of the White Amur to Control Aquatic Plants	
Report CR-A-76-1.	Production of Monosex White Amur for Aquatic Plant Control
Report CR-A-76-2.	Biological Control of Aquatic Weeds with Plant Pathogens
In Publication	
	Evaluation of Herbicide Application Platforms for Aquatic Plant Control; Report 1, Evaluation of Marsh Screw Amphibian (MSA)

This last item is a recent innovation of the program. A large-scale operations management test is a field test of a proposed aquatic plant control technique conducted on a selected large area, at a scale and in a manner representative of a full-scale field operations activity. The test is conducted cooperatively by both laboratory basic research personnel and field operations personnel, and its purpose is to adapt basic laboratory and experimental research results to the field and to integrate them into the operations program. It differs from a pure research experiment both in scale and in minimum experimental controls that are imposed on the variables that may affect the outcome of the experiment. It differs from a pure operational project in that the results are carefully monitored over a period of time to determine, first,

whether the experimental agent (or procedure) is in fact cost-effective at the scale of field operations, and second, whether significant undesirable changes may occur in the test area ecosystem as a result of the experimental plant control technique.

The first use of this type of field test by the WES involves the use of the white amur fish in Lake Conway, Florida. The overall structure of this test is such that it includes a very comprehensive data collection effort directed toward the goal of assessing not only the effectiveness of the fish as a control agent, but also the ecosystem responses. In addition, a predictive model is being developed that, when completed, will enable both scientists and managers to extrapolate the results of this and perhaps previous tests to other problem areas. The Lake Conway effort is the first in a series of large-scale tests being planned. For example, it is expected that in fiscal year 1978, a second test, with insects and pathogens, will be initiated in Louisiana. A third test is in the preliminary planning stages for initiation in fiscal year 1979 to evaluate the use of slow-release herbicide formulations. The basic overall approach of the Lake Conway test will be followed for the design of these future tests.

The Corps Aquatic Plant Control Research Program will continue to direct future research toward objectives that are clearly identifiable with operational needs. In addition, these research elements will be couched in terms of specific plans to place operational capabilities in the districts' control programs in a defined time frame. Obviously, the operational control programs will also undergo change in order to incorporate this problem-solving attitude.

The solutions resulting from these efforts must be designed to solve an aquatic plant problem at levels defined by the public users of our waterways. The burden of being successful lies with well-managed long-sighted control programs with true problem-solving tools provided by research.

STATUS OF EPA REGULATIONS OF AQUATIC HERBICIDES

by

J. G. Cummings*

In this presentation all the items in Tables 1 and 2 were discussed.

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Table 1
Aquatic Pesticides for Which Regulations Have Been Issued as of 14 October 1976

Pesticide	Sponsor	Use	Restrictions	Tolerances
Copper Sulfate Pentahydrate	Cities Serv. & Phelps Dodge Refining	Lakes, ponds, and reservoirs	None	1 ppm in potable water Exemption from requirement of a tolerance for [illegible] CFR 123.90 and 180.1021
	Bur. Recl.	Irrigation conveyance systems	Under the supervision of Bur. Recl.	
Basic Copper Carbonate (malachite)	3 M	Impounded and stagnant bodies of water	Treated areas must be left undisturbed for 48 hr following treatment	
Copper Triethanolamine	Applied Biochemists	Fish hatcheries, lakes, ponds, and reservoirs		
Xylene	Dept. of Interior	Irrigation conveyance systems	Used only in programs of the Bur. Recl. and cooperating water user organizations Initial concentration not to exceed 750 ppm Not to be used where water is source for potable water system or where return flows of such treated irrigation water would contain residues in excess of 10 ppm Xylene to be used shall meet requirement limiting the presence of a polynuclear aromatic hydrocarbon as listed in Sec. 121.1203(b)(3)	Exemption from requirement of a tolerance when used in irrigation conveyance system
2,4-D (dimethylamine salt or BEE) ester	TVA	Watermilfoil TVA system	Not to be used within a half mile of potable water intakes	1.0 ppm in fish 0.1 ppm in potable water CFR 180.142 and 123.100
Simazine	Ciba Geigy	Farm ponds with little or no runoff	Treated water cannot be used for irrigation, domestic purposes (including livestock watering) for 12 months following treatment	12 ppm in fish 0.01 ppm in potable water CFR 123.400 and 180.213a
2,4-D (dimethylamine salt)	Corps of Eng.	Ponds, lakes, reservoirs, marshes, bayous, canals, rivers, and streams that are quiescent or slow moving	Limited to programs of the Corps of Eng. or other Federal, state, or local public agencies Treated water may not be used for 3 weeks after treatment for domestic or irrigation purposes unless an approved assay shows that water contains no more than 0.1 ppm 2,4-D	1.0 ppm in irrigated crops 1.0 ppm in fish and shellfish 0.1 ppm in potable water CFR 123.100 and 180.142
2,4-D (dimethylamine salt)	Bur. Recl.	Irrigation ditch banks in the western U. S.	Programs of the Bur. Recl. Cooperating water user organizations; Bur. Sport Fisheries; Agricultural Research Serv., Corps of Eng. Restrictions against grazing of livestock on treated ditch banks and against fishing in treated waterways	0.1 ppm in irrigated crops 0.1 ppm in potable water CFR 123.100 and 180.142
Diquat	Chevron			0.01 ppm in potable water (Interim tolerance) CFR 123.160
Endothall	Pennwalt			0.2 ppm in potable water (Interim tolerance) CFR 123.180
Methoprene	Zoecon	Mosquito control		Exempt from requirements of a tolerance in potable water CFR 123.285
Brominated resin	Everpure			1 ppm for residual bromine in potable water CFR 123.251

Table 2

Petitions for Aquatic Uses Currently Under Agency Review or in Abeyance (14 October 1976)

Pesticide	Petitioner	Use	Status
Dimilin	Thompson-Hayward	Mosquito control	Active review
Diquat (6,7-Dihydrodipyrido(1,2-a:2',1'-c) pyrazinediium (salt))	Corps Eng.	Ponds, lakes, slow-moving water	Draft order in preparation
Endothall (3,6-Endoxohexahydrophthalic acid)	Pennwalt	Lakes, ponds, irrigation ditches, canals	Abeyance*
Glyphosate (N-(Phosphonomethyl)glycine)	Monsanto	Irrigation water	Active review
2,4-D BEE (Butoxy ethanol ester of 2,4-D)	Corps Eng.	Hyacinths, ponds, lakes, slow-moving water	Abeyance
Silvex 2-(2,4,5-Trichlorophenoxy) propionic acid	Corps Eng.	Hyacinths, ponds, lakes, slow-moving water	Abeyance (dioxin problem)
Dichlobenil (2,5-Dichlorobenzonitrile)	Thompson-Hayward	Farm ponds, fish farming, other bodies under control of user	Abeyance
Dalapon (2,2-Dichloropropionic acid)	Bur. Recl.	Irrigation ditch bank	Active review
Fenac (2,3,6-Trichlorophenylacetic acid)	Amchem	Flowing and nonflowing water, lakes and ponds with low exchange	Withdrawn
Endothall (3,6-Endoxohexahydrophthalic acid), aluminum salt	3 M	Nonflowing water in lakes, and stagnant canals and waterways	Active review
4-nitro-3-trifluoromethylphenol, sodium salt	Fish & Wildl. Serv. USDI	Lampricide in tributaries to the Great Lakes	Active review**
Methyl parathion	State of Calif.	Clear Lake gnat	Active review

* Abeyance—petition for tolerances has been denied pending submission of supplemental information.
** With the exception of this lampricide, all the above are herbicides.

CURRENT STATUS OF THE AQUATIC PLANT CONTROL PROGRAM IN TEXAS

by

C. O. Martin* and W. T. Nailon**

INTRODUCTION

Current aquatic plant control activities in the Galveston District include primarily the control and progressive eradication of waterhyacinth (*Eichhornia crassipes*) and alligatorweed (*Alternanthera philoxeroides*). The program is a cooperative cost-sharing and contractual arrangement between the Federal Government and local interests, as described by Novosad and Nailon[1] and Novosad et al.[2] The Corps of Engineers, Galveston District, represents the Federal Government, and the Texas Parks and Wildlife Department represents the State of Texas as the local cooperating agency. Field operations are carried out by the Texas Parks and Wildlife Department in accordance with mutually established geographical priorities in consonance with the Galveston District's approved General Design Memorandum.

This report represents a summary of the present status of the Aquatic Plant Control Program in the State of Texas. Currently utilized eradication and control procedures and the status of operations in each work area are described in the following sections.

ERADICATION AND CONTROL PROCEDURES

Waterhyacinths

Waterhyacinths continue to be among the most serious of aquatic plant pests in Texas. According to Guerra,[3] 28,933 acres of hyacinths have been eliminated in eight watersheds since 1970. Infestations are now considered to be under manageable control except in portions of the North Coastal Area. Nevertheless, routine treatment with herbicides is necessary during the growing season to keep infestations to a minimum. Control measures involve the use of EPA-approved formulations of 2,4-D (dimethylamine salt of 2,4-dichlorophenoxyacetic acid) with appropriate spreader sticker additives to insure good adhesion to plants. The herbicide is applied at a maximum rate of 4 lb in 100 gal of water to the surface acre.

Alligatorweed

Infestations of alligatorweed have increased in recent years throughout many regions of the Texas Coast. Control methods to date have involved primarily the use of Agasicles flea beetles (*Agasicles hygrophila*). Although flea beetle populations have been introduced at various locations in five work areas since 1970, their weed destruction capabilities have met with limited success in Texas. Guerra[3] reported the following factors as reasons for failure of biological control methods: erratic weather conditions over the past several years, frequent delayed winters, frequent rains, and cool spells during

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peak flea bettle growth periods. Additional factors that have stimulated the growth and spread of alligatorweed include a general increase of nutrient levels in Texas basins, the creation of new reservoirs, which have provided additional areas for increased growth, and the paucity of chemical control activities.[3]

Future eradication and control of alligatorweed in Texas will consist of an integrated program employing herbicidal treatment and continued introduction of flea beetles. Herbicidal formulations and application procedures will be the same as described for waterhyacinths. Inroduction of beetles will depend upon the appearance of new plant growth and the availability of flea beetles.

TEXAS WORK AREAS—CURRENT STATUS

The State of Texas was originally divided into 18 work areas for operational convenience in implementing the Aquatic Plant Control Program. These areas are oriented to the watersheds of major river basins and coastal drainage systems. Current control activities are presently limited to the lower portions of 10 of the work areas as described by Novosad and Nailon.[1] Aquatic plant control operations in Federally owned reservoirs within these work areas are generally accomplished with operation and maintenance funds rather than under the Galveston District's Aquatic Plant Control Program. Treatment of lakes shared by Texas and Louisiana involve coordinated efforts of the Galveston and New Orleans Districts and state cooperating agencies. The following paragraphs summarize the present status of waterhyacinths and alligatorweeds in each work area (also designated Work Orders 1 through 10). Table 1 shows estimated yearly acreages of these species in each area from 1971 to July 1976; data were not available for 1972 and 1973.

Nueces River Basin. Although approximately 8000 acres of waterhyacinths occurred in lower portions of the Nueces River Basin prior to 1970, subsequent control operations reduced these infestations to 200 acres by 1971.[1] Presently only about 50 acres of hyacinths exist in the Nueces River Basin.

Guadalupe River Basin. Primary infestations of waterhyacinths in the Guadalupe Basin occur in the lower river bottomlands and marshes immediately above the influence of saltwater intrusion. Other localized populations exist along the river between the cities of Gonzales and New Braunfels. Acreages of hyacinths have been reduced from approximately 2000 acres in 1971 to 100 acres at present.

North Coastal Area. Infestations of waterhyacinths total 3000 acres in the North Coastal Area in 1971. Extensive treatment has brought the present populations to approximately 500 acres, but hyacinths continue to be a serious problem in certain bayous and watersheds. Lower reaches of Taylors Bayou, including the J. D. Murphree State Wildlife Management Area, often suffer recurrent outbreaks of waterhyacinths. Alligatorweed in this region has increased from 2000 acres in 1971 to approximately 4000 acres in July 1976. However, in one small portion of the North Coastal Area near Rosenberg and Sugar Land in Fort Bend County, there have been definite signs of flea beetles reducing alligatorweed to a point near extinction.[3] Good success with flea beetles has also been obtained on portions of Oyster Creek in southern Brazoria County.

Sabine River Basin. Original concentrations of waterhyacinths occurred primarily in Toledo Bend Reservoir. Infestations in 1971 totaled approximately 5000 acres, most of which were in the reservoir area. Waterhyacinth outbreaks also occasionally plague the lower reaches of the basin. Approximately 1000 acres were reported for the work area in July 1976. Alligatorweed populations have increased from 1500 acres in 1971 to about 3000 acres at present.

Trinity River Basin. Approximately 1000 acres of waterhyacinths now occur in the Trinity River Basin compared to 2450 acres in 1971. Major populations have been considerably diminished, but problem areas still exist in the many sloughs, bayous, and old river channels. Major concentrations

Table 1
Estimated Acreages of Waterhyacinths and Alligatorweed in Texas (1971-1976)

Work Order	Area or River Basin	1971	1974 1 Aug	1975 20 Aug	1976 9 Jul
		Waterhyacinths			
1	Nueces River Basin	200	25	150	50
2	Guadalupe River Basin	2,000	1,000	150	100
3	North Coastal Area	3,000	2,000	300	500
4	Sabine River Basin	5,000	5,000	500	1,000
5	Trinity River Basin	2,450	2,000	2,500	1,000
6	Neches River Basin	800	800	500	200
7	Cypress Creek Basin	100	95	100	50
8	South Coastal Area	500	500	75	50
9	San Jacinto River Basin	700	700	2,000	3,000
10	Rio Grande Basin	5	5	10	25
	Total Acreage	14,755	12,125	6,285	5,975
		Alligatorweed			
1	Nueces River Basin	--	--	--	--
2	Guadalupe River Basin	--	--	--	--
3	North Coastal Area	2,000	1,800	4,000	4,000
4	Sabine River Basin	1,500	1,500	2,000	3,000
5	Trinity River Basin	3,000	3,000	3,000	6,000
6	Neches River Basin	400	400	750	2,400
7	Cypress Creek Basin	--	--	--	--
8	South Coastal Area	--	--	--	--
9	San Jacinto River Basin	1,500	1,500	1,500	3,000
10	Rio Grande Basin	--	--	--	--
	Total Acreage	8,400	8,200	11,250	18,400

are in the vicinity of Lake Livingston, but only minor, sporadic populations are found in the lower portion of the delta. Alligatorweed infestations have doubled since 1971. Most of the present 6000 acres occur in the lower Trinity River delta and have displaced much of the natural vegetation of fresh and brackish marshes. The first release of flea beetles in the Wallisville area occurred in 1975. However, the species evidently migrated into the region from other sites prior to this release as they were observed in the area in 1974. Little evidence of beetle activity was observed in the area in 1975 and throughout most of 1976. However, during a survey in early September 1976, considerable flea beetle activity was noted, and alligatorweed populations appeared much reduced from previous months. Evidence of plant destruction by the phycitid moth (*Vogtia malloi*) was also observed, although this species has not been released in the area under the Galveston District's Aquatic Plant Control Program. We assume that these moths have migrated from distant localities where they have been introduced as a means of control by other agencies.

Neches River Basin. Waterhyacinth infestations in this region are now limited to approximately 200 acres, most of which are in Federally owned Steinhagen Lake (Dam B) and in the bayous of the lower portion of the basin above Sabine Lake. Alligatorweed populations have exploded from 400 acres in 1971 to about 2400 acres in 1976. The first release of the Agasicles flea beetle in Texas was in May 1967 at Dam B.[4] According to Guerra,[3] flea beetles have been introduced in large colonies of 4,000-5,000 adults at Dam B, and some 158,000 adults were introduced in this area in 1974. Biological control methods in this region, however, have produced limited results. Detailed treatment of aquatic plants at Dam B was discussed by Hambric et al.[5]

Cypress Creek Basin. The only serious infestation of waterhyacinths in this region consists of 50-100 acres in Caddo Lake on Big Cypress Creek. Periodic herbicidal treatment is employed to control recurrent growth. Alligatorweed is not currently a problem in the basin.

South Coastal Area. Some 50 acres of waterhyacinths presently exist in the southernmost work area of Texas. Most populations occur in resacas (old riverbeds) and in drainage and irrigation canals in Cameron County.

San Jacinto River Basin. Infestations of waterhyacinths have increased from 700 acres in 1971 to approximately 3000 acres at present. The species continues to be a problem on Lake Houston, which is a source of water supply for the city of Houston, and in the many irrigation and water supply canals in the area. Major alligatorweed populations also occur in the Lake Houston area and in wetland regions along tributaries of the San Jacinto River. Approximately 3000 acres of alligatorweed now occur in the basin.

Rio Grande Basin. This basin is the least infested work area in Texas. Approximately 25 acres of hyacinths exist on San Felipe Creek near Del Rio. Alligatorweed has not been reported for this region.

CONCLUSIONS

The existing Aquatic Plant Control Program for the State of Texas entails primarily the eradication and control of waterhyacinths and alligatorweed, which are considered to be the most troublesome aquatic weeds in the state. Infestations of waterhyacinths are generally under manageable control except in portions of the North Coastal Area. Herbicidal treatment involves the use of EPA-approved formulations of 2,4-D with appropriate additives applied at a maximum rate of 4 lb in 100 gal of water to the surface acre. Alligatorweed populations have increased dramatically throughout much of the Texas Coast. Past control methods have involved almost entirely the use of the Agasicles flea beetles, but biological control agents alone have produced limited results. Future techniques will consist of an integrated program using herbicidal treatment and continued introduction of flea beetles.

Current operational activities in Texas are concentrated in the lower portions of 10 work areas. The Trinity River Basin, North Coastal Area, and Sabine River Basin are the most critical regions at this time. Intensive efforts are required to control waterhyacinths in the Trinity, Sabine, and North Coastal areas. Infestations of alligatorweed are most intense in the Trinity, North Coastal, Sabine, and Neches work areas.

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STATUS OF RECONNAISSANCE SURVEY REPORT AND REVIEW OF AQUATIC PLANT PROBLEMS IN THE STATE OF OKLAHOMA

by

L. M. Mason*

RECONNAISSANCE SURVEY REPORT

A reconnaissance survey of aquatic plant infestations in lakes and navigable waterways of Oklahoma was made during the summer of 1975. The survey report was submitted to the Southwestern Division Office for approval and was returned to the district for necessary revisions. It is anticipated that the revised reconnaissance survey report will be resubmitted to the Southwestern Division Office for approval by 1 May 1977.

STATEMENT OF PROBLEM

There is an aquatic plant problem in certain lakes and streams of Oklahoma. Aquatic plants have interfered with boating, swimming, fishing, and flow of water and have substantially decreased use of municipal water supply and irrigation reservoirs. Interference with navigation and potable water supplies for municipalities is an ever potential problem. At present, the most obnoxious plant species in Oklahoma is Eurasian watermilfoil. Estimates made in 1975 of Eurasian watermilfoil infestations were approximately 8206 acres in 12 major impoundments (Table 1). Most of these waters represent important resources to the cities involved and are essential to the development of the state as a whole. Without control programs, these infestations are threats to other bodies of water, including Federally controlled impoundments. Presently, there are 23 major areas of aquatic plant specie infestations throughout the State of Oklahoma (Figure 1); however, this paper will deal only with infestation of Robert S. Kerr Lake, a Corps project.

EURASIAN WATERMILFOIL INFESTATION IN ROBERT S. KERR LAKE

The Eurasian watermilfoil infestation in Robert S. Kerr Lake was first observed in 1971. Prior to that time, there were frequent reports that small patches of a strange aquatic plant were hampering fishermen in the Illinois River, a tributary of the Arkansas River located in the upper part of the lake. Since those early reports, the Eurasian watermilfoil has spread from the Illinois River downstream some 18 miles into the main body of Robert S. Kerr Lake. Today's estimated acres of infestation is around 600, a 100 percent plus increase over the 1975 figure of 328 acres.

Because this plant can propagate so easily and rapidly, it poses a serious threat not only to Oklahoma waters but to the entire McClellan-Kerr Navigation System. From this source the entire system from Tulsa to New Orleans could be "sprigged" with watermilfoil in a short period of time. Large barge traffic may never be seriously hampered, but the infestations constitute a threat to other

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Table 1
Known Eurasian Watermilfoil (Myriophyllum spicatum) Infestations in Oklahoma Waters, 1975

Lake	Location	Estimated Acres	Year First Observed	No. on Map
Lake Carl Etling	Kenton	35	1968	1
Fort Cobb Reservoir	Fort Cobb	1200	1969	2
Wichita Mountains Wildlife Refuge Lakes and Ponds (30)—includes Lake Elmer Thomas	Cache, Lawton, Medicine Park	700	1965 or earlier	3
Lake Lawtonka	Lawton	3	1974	4
Lake Humphries	Duncan	516	1964	5
Clear Creek Lake	Duncan	72	1965	6
Soil Conservation Lakes (2)	Duncan	210	1972	7
Lake Thunderbird	Norman	3642	1973	8
Lake Stanley Draper	Oklahoma City	290	1967	9
Shawnee Twin Lakes	Shawnee	1085	1968	10
Chandler Lake	Chandler	125	1964	11
Robert S. Kerr L&D and Reservoir	Sallisaw	328	1970	12
	Total Acreage Infested	8206		
	Acreage NOT under jurisdiction of Corps of Engineers or other Federal agency	2336		

commercial activities, recreational uses, and human safety up and down the navigation system where extensive growths occur. An example of the present interference caused by the Eurasian watermilfoil is at the confluence of the South Canadian and Arkansas Rivers where the mouth is already blocked to large watercraft due to the heavy growth. In addition, a marina concession located in the Applegate Cove of Robert S. Kerr Lake has experienced difficulty in keeping the plants out of the wet storage docks and keeping boat lanes open from the cove to the lake during the summer of 1976. These problems were totally nonexistent just 2 years ago.

To date, no control methods have been taken to combat the continued expansion of the Eurasian watermilfoil in the Robert S. Kerr Lake; however, it is obvious that some action is necessary. Since this type of problem is new to our district, we are searching for answers to the following questions on how much control should be exercised, at what point in time should control actions be started, are funds available for a control program, what coordination is required prior to initiating control work, what types and amounts of herbicides are required to obtain effective control, etc. The answers we are seeking must be forthcoming in the near future if we are to react in time to prevent loss of certain project benefits due to excessive plant growth within the navigation channel.

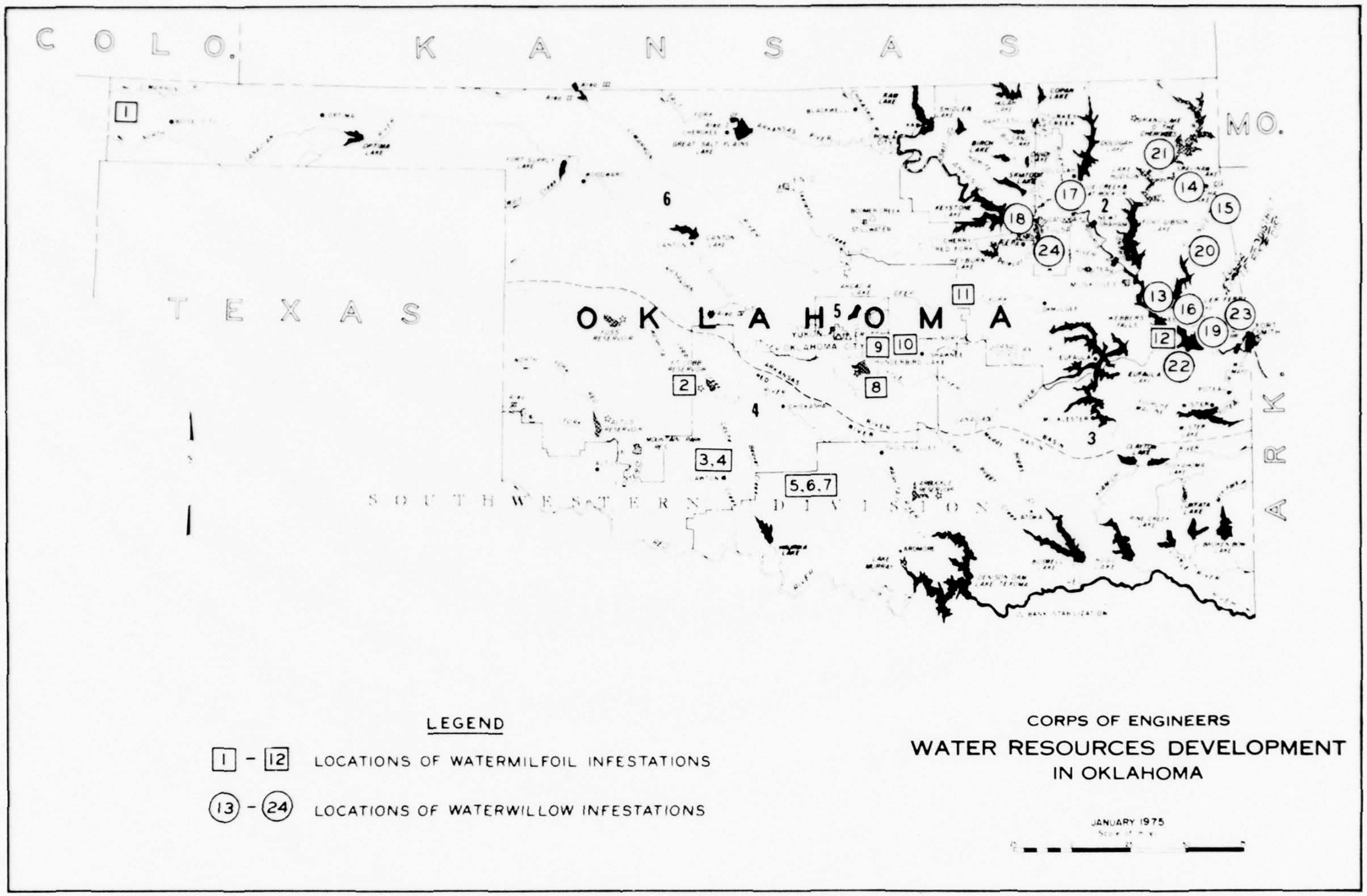

Figure 1. Aquatic weed reconnaissance survey in Oklahoma

EAST TEXAS RESERVOIRS—AQUATIC PLANT CONTROL

by

E. J. Moyer*

SUMMARY

In the deep east-central Texas area, aquatic plants thrive under similar favorable environmental conditions as exist in the neighboring State of Louisiana. Here are evident a long growing season, marshy environment, and hot humid climate with an average annual rainfall of 52 in. Inundated timber, dense tree canopy, and shallow waters of the reservoirs in this region increase the opportunities for aquatic plant growth. Northern sectors of the reservoirs are hard to penetrate or reach by most methods of herbicide application techniques. Elsewhere in the district the conditions mentioned above, both climatic and environmental, are not as well met nor as consistently met, and aquatic weeds do not grow as profusely.

GENERAL

The Fort Worth District has 17 operational and maintenance reservoirs generally scattered about the eastern two thirds of the state with 75 percent of the projects located on either the large Trinity or Brazos River systems. Of the 17 reservoirs we really have only two that experience significant aquatic plant problems such that an annual control program is required. These are the Town Bluff Dam-B. A. Steinhagen Lake and the Sam Rayburn Dam and Reservoir, both located in deep east-central Texas. This east-central Texas area is quite a bit different from the rolling hills, grassland prairies, blackland prairies, and post oak country prevalent in Texas. Instead, the east-central Texas area is a land of erodible sandy loamy soils and extensive tracts of pine forests interspersed with some hardwood stands. This type of area resembles the State of Georgia more than Texas. Similarly, the northern sectors of the reservoirs are in a marshland environment, which one might associate more with the Louisiana backlands than with Texas. In these northern sectors there exists a primitive atmosphere; an area of solitude little visited by man except for transient excursions. It is in areas such as those described that our aquatic plant problems seem to originate, with many aquatics harboring in these areas, unmolested and ready to disperse, break loose, and become established further down the reservoir proper. We might aptly call these areas extensive nursery grounds for birds, reptiles, amphibians, mosquitoes, and aquatic plants.

Many aquatic weeds abound in the reservoirs; however, the most conspicuous and immediate problem aquatics are waterhyacinths and alligatorweed. Problems occasioned by their presence include interference with navigation, impediment of incoming flows, instigation of complaints from marinas and subdivision properties through waterhyacinths drifting into cove areas, and to a lesser extent, providing a favorable environment for the development of mosquitoes. The Town Bluff Dam-B. A. Steinhagen Lake has appreciable quantities of both aquatics, whereas the primary problem at the Sam Rayburn Reservoir is waterhyacinths.

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FIRST DISTRICT AQUATIC PLANT CONTROL PROGRAM

The earliest significant aquatic plant control program in the district was initiated at the B. A. Steinhagen Lake back in 1963, approximately 10 years after the lake was completed. At that time, there were about 200+ acres of waterhyacinths in the lake according to old reports. Over the years, this figure has increased to approximately 1000-1500 acres of waterhyacinths and 600 acres of alligatorweed. The chemical that has been used for most all control programs has been the amine formulation of 2,4-D applied at the various rates of 2 to 4 lb of the acid equivalent per acre. The chemical was put out as invert emulsion to prevent drift, and the mode of application was a spray boom mounted on a helicopter. All contracts were placed for low bid. With one exception, there has been an annual aquatic plant control program here since 1963. All treatments generally resulted in an 85 to 90 percent control.

The first aquatic plant control program for Sam Rayburn began back in 1965, the first year of impoundment, at which time there were about 500 acres of waterhyacinths. However, many years were skipped until the second program began in 1971. The same chemical and mode of application was used at the B. A. Steinhagen Lake. Since 1971, there has been an annual aquatic plant control program, with an average of 2000 acres of waterhyacinths treated.

PROBLEMS ENCOUNTERED WITH AQUATIC PLANT CONTROL PROGRAMS

Fall Application Programs

In the early years of project operations, it was standard operational procedure to treat aquatic plants in the fall months. A good kill of aquatics was made at this time, and spraying operations were favored by many days of 72° F, not uncommon in early fall in this section of the state. However, it is equally true that some of the treatment programs extended into late fall and partial winter treatments when the results of aquatic spraying were questionable.

Monies Available

In the early years of project operations, aquatic plant control had to be squeezed into the budget from the two projects as a line item allocation. Once in, this became an annual self-perpetuating cost item subject then to the project managers' decisions and foresight as to whether or not an aquatic plant control program would be planned for the next year, and if so, how much money would be allocated for this job. There were a lot of conflicting jobs that had to be done, and one of major significance was erosion control work of the lakes shorelines. Project managers had to balance their priorities. The aquatic weed problem really didn't look too bad at this time. There may have been instances of robbing Peter to pay Paul to get both jobs done, at least on a minimal basis. This may well have been the precipitating factor that made project managers go with fall application, as the cost for aerial application work during this "off season" was less than would be possible under the peak season work and higher costs of spring treatments.

Because our reservoirs are in an operational and maintenance status, we get no funding for aquatic plant control from the Federally sponsored Aquatic Plant Control Program, except under experimental programs. To date, we have not been able to describe our programs as experimental. However, fortunately we are or have been getting the last several years good appropriations from our project

managers, enough to cover the costs of a program whereby we maintain a 90 percent control over aquatic plants on an annual basis.

State-Federal Contract

Our most recent problem occurred when we had the good opportunity to enter into a 70-30 cost-sharing program for aquatic plant control with the Texas Parks and Wildlife Department. Under this contract the state would provide 30 percent of the cost of the control program. This was good economically. The major difference between this contract and the previous contract was the state crews would be using the conventional boat-spraying gear as opposed to the aerial application method by previous contracts with commercial concerns. The state-trained crews would be on our lakes for around 3 to 3-1/2 months. This was a benefit, particularly concerning treatment of the Sam Rayburn Reservoir. At this reservoir, we receive many complaints from marinas and subdivision areas about drifting in of aquatics. With the state crews on the lakes over an extensive period of time, we can direct them, if needed, to those infested areas of the reservoir at the time drifting problems occur. This was not the case with aerial applications where we had the job for both reservoirs completed in about a 4-week period. If any problems of this nature developed after the 4-week period, we would have to arrange a new contract with new costs, and then await the necessary administrative procedure. A third factor that we liked about the mobile crews was the ability of their trained crews to spot any new or exotic introduction of weeds into the lake. As most people know, the aquatic weed hydrilla has been in Lake Livingston. As both of our reservoirs are located within a 100-mile radius of Lake Livingston, it is not unreasonable to be suspicious of the weed getting into nearby Corps of Engineers lakes.

We were a bit apprehensive about the state contract because of the conventional boat treatment. The question was could they get back into the sloughs, bayou areas, and log jam areas and get adequate treatment to the aquatics? However, we did have favorable reports from the Galveston District, Corps of Engineers, on a similar contract with the state and spraying operations done under very similar conditions.

The first year the cost-sharing program got under way was 1975. We have a contract for this year also and hope to do so the next year. What we don't want to do is treat one year and then wait a few years until we face another problem. We want to keep a steady pressure on the populations from year to year, thus in the long run saving money and using less chemical in the lakes.

We are getting comparable results with the state crew work as that experienced with aerial applications, i.e. a 90 percent control.

The problems with the contract were getting it off the ground. Since we were not sure whether we were authorized to enter into a cost-sharing contract of this type, we wrote to Office, Chief of Engineers (OCE), to approve this procedure. Also about this time, our district received word, as did all districts, that 2,4-D was no longer approved for our reservoirs, except under special need, in which case a letter or request for exception would have to be sent to OCE and Environmental Protection Agency (EPA) for final approval or disapproval. We did receive word back that we were authorized to enter into a cost-sharing program with the state, but we still had to do something about the restriction on 2,4-D. Subsequently, we did send in a letter of exemption and received EPA approval, with the major point made that only the amine formulation of 2,4-D was to be used. We finally got the 1975 cost-sharing contract started in late summer.

In 1976, we received the new modification of the Aquatic Plant Control Program for Operations

dated 1 February. This Engineer Regulation 1130-2-412 did have written in a stipulation approving cost-sharing contracts. About this time, we also received word that the Weedar 64 Formulation of 2,4-D was authorized for use in our reservoirs. The next step was to have Contract Administration and Legal Department secure this contract with the state in time for a spring application program. However, the Engineer Regulation (ER) was not signed, for it was a draft copy. Thus, we did have to wait a few months before the signed copy arrived. In June we finally got the contract under way.

So it has been frustrating, but we are slowly backing up in seasonal applications from the fall months to initiating the contract in the summer months. Next year, hopefully, we will have the program back up to starting in the spring months where it belongs.

BRIEF DESCRIPTIONS OF THE TOWN BLUFF DAM-B. A. STEINHAGEN LAKE AND SAM RAYBURN DAM AND RESERVOIR

As Steinhagen Lake and Sam Rayburn Reservoir represent the major portion of our aquatic plant control in the district, this section will indicate briefly characteristics of the projects and their interrelations of operations.

B. A. Steinhagen Lake, which was completed in 1953, has a surface area of 13,700 acres. It is located on the Neches River; however, the Angelina enters the Neches forming a confluence and confluent area at the immediate north end of this lake. Steinhagen Lake is a shallow lake with an average depth of 6 ft and with only 2-ft vertical mean sea level elevation between the top of its conservation pool elevation and the top of its dam before overspill. The combined Neches-Angelina River Basin is one of the most voluminous flow systems in the state. Since we have a relatively small and shallow lake handling some large inflows, consistent regulation of the dam gates is necessary. To further point out the necessity for consistent gate changes is the fact that Sam Rayburn Reservoir is located only 25 river miles upstream on the Angelina River. This reservoir completed in 1965, has a surface area of 114,400 acres, and makes releases for water conservation, flood control, and hydroelectric power generation. All these releases must be handled by Steinhagen Lake, plus the normal flows on the large but somewhat sluggish Neches River. Town Bluff Dam-B. A. Steinhagen Lake, by virtue of its small size and operational procedure for water releases with Sam Rayburn Dam has been termed a reregulating device or "surge tank" to handle, receive, and discharge as soon as possible the various inflows mentioned.

Sam Rayburn Dam and Reservoir, being much larger than Steinhagen Lake, is more stabilized relative to water-level changes. It would take many days of heavy rainfall and/or discharges to effect a significant water-level change. Likewise, water releases for hydroelectric power generation and water conservation are not particularly depleting at any one time.

Conversely, Steinhagen Lake, since its first full impoundment, has been nearly dry several times. It has not been as subject to debilitating low elevations since Sam Rayburn was constructed; however, there is a degree of erratic flows as occasioned by Sam Rayburn releases. Generally, Steinhagen Lake fluctuates 2 to 3 ft below the top of the conservation pool and back up; however, there is a high frequency of such changes.

Steinhagen Lake also has numerous underwater mud flats located in the northern half of the lake. These flats may have possibly provided a stepping stone for the movement of alligatorweed from the marshy confluence area outward into the lake proper. As these mats grew, they extended laterally appreciably, with the end result of a convergence of many mats closing in the waterways in this section of the lake.

OTHER AQUATIC CONTROL DEVELOPMENTS

The alligatorweed flea beetle was introduced into Steinhagen Lake in 1967 by the Texas Parks and Wildlife Department and the U. S. Department of Agriculture. My first year here I did see many of the beetles in various growth stages; however, they were quite spotty in distribution. Many of them were in the slough areas. However, you could see good attack on one mat of alligatorweed, and then a few feet away another mat would be relatively untouched. So their introduction has augmented our control, but the major emphasis is still on the chemical use of 2,4-D. Why the beetles have not developed to more abundance we do not know. Possibly cooler weather or fluctuations of water elevations whereby developmental stages have been covered and drowned by the rising water may be the cause.

The second development that was tried was a lake drawdown. For many years, a request was placed with the Lower Neches Valley Authority, which is the state-approved Water Rights Permittee for water releases (resources) from the two reservoirs. In all cases the request was turned down. However, recently, we finally did receive their approval. The drawdown was planned for erosion control, dam repair, and hopefully a winter kill on aquatics, which did not work out. The first problem encountered was that we could not keep the water elevation down to the desired level because of operational releases that had to be made from Sam Rayburn and also rainfall in the Neches watershed upstream. A lot of complaints of flooding and some property damage were received downstream from property owners. Encroachment of private owners into the floodplain below the Sam Rayburn and Town Bluff Dams has occurred over the years, and these were the people who complained. An attempt to discharge to get back down to the desired level was abandoned.

Other complaints were raised from hunters, fishermen, and people interested in the water-oriented recreation. Complaints were received by telephone and mail, including congressional inquiries. Banks of the Angelina River consist of a sandy alluvial-type soil that is highly erodible. When any large amount of bank is exposed on these drawdowns, the pressure created by a fast drawdown of the hydroelectric power turbines at Sam Rayburn Dam causes large amounts of bank to slough off into the river. One presidential and many congressional inquiries have been received from property owners along the banks of the Angelina River. When power is made daily, there is just not enough time to reduce or stop this type of erosion.

The main point is that if the reservoir were the only reservoir on the river system, the drawdown might have been completed. However, when it has to contend with upstream reservoir operational discharges and complaints of bank erosion and damage to properties, there is just not much headway toward coordinating a successful drawdown for any length of time.

FUTURE

In the near future, we are thinking about purchasing and fitting a boat equipped for handling invert emulsion sprays, underwater applications of liquid formulations, and granules. This boat would be centrally located at one select project and be available for use by any of the reservoirs for treating aquatic weeds. This would be particularly adaptable for treating the several reservoirs where we are beginning to get some significant growths of submerged aquatics, notably watermilfoil. It would probably not be used at Sam Rayburn or Town Bluff except for some maintenance touchup after the state crews have finished. We will be discussing this with the Texas Parks and Wildlife Department and soliciting their help about the proper equipment needed for the job. Our certified reservoir ranger personnel would

undertake the work. The program, if initiated, would be fully coordinated with the Texas Parks and Wildlife Department and the Texas Department of Agriculture.

NEEDS

One need is to have our authorities, if at all possible, red tag any new ER on the Federal Aquatic Plant Control Program for Operations such that the review period would be out of the way and the official ER signed and ready in the spring of the year. Thus, if there are any new or critical amendments, Operations would be aware of them and write them into the contract, if necessary.

Another boon to Operations people would be to have an official report from the EPA on the status of herbicides, particularly in the aquatic environment. There are so many directives, bulletins, and writeups on this and that chemical that it does get confusing. An official biannual report of this nature would be desirable. Also, a composite report attending the chemical sheet listing pertinent to recording Federal Register requirements and regulations for herbicide programs would be a big boon, as these reports seem to get scattered about, or because their vast numbers seem impenetrable.

This question of treating aquatic environments with chemicals is a real hesitant one. We need to be informed and supplied with official and as up-to-date material as possible, and this supplemented as soon as possible.

AQUATIC PLANT CONTROL PROGRAM IN THE ST. PAUL DISTRICT

by

D. E. Wadleigh*

Although the North Central Division has been aware of the Aquatic Plant Control Program for some time and has made attempts to institute the program, most of these attempts have died for lack of local interest. In most cases the supply of water bodies suitable for recreation or other uses has exceeded the demand to the extent that problem areas could be avoided.

The inland lakes are most numerous in the glacial outwash areas along the southern edge of the Great Lakes. This lake area is in a band several hundred miles wide stretching from northern Minnesota around Lake Superior, across northern Wisconsin, through the Upper Peninsula of Michigan, and across the northern half of the Lower Peninsula. With increasing development and pressure for water-based recreation, hunting, and fishing, lakes that have been inaccessible or unusable in prior years are now needed to meet the demand. Some state legislatures, Wisconsin's for example, have recognized this problem as well as the problem of lakes becoming eutrophic and have created state programs to deal with them.

In the North Central Division, the St. Paul District has the most active Aquatic Plant Control Program, so I would like to limit the rest of this presentation to our efforts.

The problems most often brought to our attention in St. Paul deal with lakes that are experiencing recreational pressure and becoming eutrophic or overgrown with rooted aquatics. This applies also to reservoirs. The problem vegetation is usually blue-green algae (aphonizominon) and the submergent rooted aquatics (potumogetons, valisneria, and ceratophyllum).

Public attitudes throughout the district strongly favor a solution other than the use of herbicides. In fact, in one problem area under study, the use of herbicides or chemicals of any type is strictly forbidden by local ordinance.** As a result, most solutions proposed are mechanical or biological.

As our involvement in the program is only recent, any discussion of kinds and magnitudes of problems and potential solutions must be very limited. We expect to draw quite heavily on research on biological control being done at the University of Minnesota, Freshwater Biological Research Institute, and on mechanical and biological control research at the University of Wisconsin, which is working under contract with the Wisconsin Department of Natural Resources, Inland Lakes Renewal Program.

The Freshwater Biological Research Institute is involved in basic research of the cell division process in blue-green algae. Recent findings indicate that the reproduction process of blue-green algae most closely resembles that of bacteria and that in the reproductive process an enzyme exists that is unique to blue-green algae and certain bacteria. It is hoped that a means can be found to slow or regulate the growth rate and the reproductive cycle of blue-green algae by manipulation of this enzyme.

The most significant advances made by the St. Paul District have been in establishing cooperative administration of the programs in North Dakota and Wisconsin. North Dakota is best termed a "water-poor" state because it has few natural lakes. These tend to be concentrated in the north-central and central portions of the state. Most of the bodies of water in the remainder of the state are reservoirs. Of

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** The Red Lake Band of Chippewa Indians does not allow the use of chemicals of any type in waters within the Red Lake Indian Reservation without a permit.

the approximately 200 lakes in North Dakota with significant recreational use or potential, about 30 have some type of plant overgrowth or accelerated eutrophication. Work is currently under way to prepare a "Plan of Approach" in cooperation with the North Dakota Game and Fish Department. This document will describe the problem areas, identify areas that may qualify for the Aquatic Plant Control Program, describe the type and detail of information available and the work needed to implement the program and control measures, and most important, establish a priority program by which these problems will be addressed.

Besides the obvious purpose of improving the state's recreational resources, North Dakota has an additional interest in pursuing the program. Some reservoirs are experiencing problems sooner than they were expected. If North Dakota is to increase its supply of surface water for recreation and other purposes, additional reservoirs are needed. Failure to attain expected visitor attendance at existing reservoir sites because of eutrophication or weed conditions reflects on the reliability of attendance estimates for other planned lake developments. Also, successful control operations at existing reservoirs could be adapted to pending or proposed reservoirs.

Wisconsin, on the other hand, has a rich natural resource in its numerous lakes and streams. The Inland Lakes Renewal Program was established to rehabilitate degraded lakes and, if possible, preserve the conditions of others not yet in danger of infestation. One interesting aspect of the program is a strong state-local partnership approach. Although the program provides technical and sometimes financial assistance, lake protection and rehabilitation must be initiated and carried out at the local level by a Lake Protection and Rehabilitation District.

In cooperation with the Wisconsin Department of Natural Resources, a "Plan of Approach" is being prepared similar to the one in North Dakota. The document will identify problems in which the Federal interest and the state and local resources most closely dovetail and make for the most efficient use of the monies available.

As I mentioned earlier, the St. Paul District is new to the program, and we have much to learn about how this authority best serves the needs of the people in our district. Close cooperation with the states appears to be working well and will be pursued. Any comments, suggestions, or helpful hints would be appreciated not only by the St. Paul District but by the other districts in the North Central Division.

AQUATIC PLANT CONTROL ACTIVITIES—OHIO RIVER DIVISION

by

C. W. Crews*

INTRODUCTION

The Ohio River Division includes all or parts of 14 states: New York, Pennsylvania, Maryland, Ohio, West Virginia, Indiana, Illinois, Kentucky, Tennessee, Virginia, Mississippi, Alabama, Georgia, and North Carolina. Four districts are included in the Division: Pittsburgh, Louisville, Huntington, and Nashville (Figure 1).

The Nashville District, of which I am part, is formed by the basins of two major rivers, the Tennessee and the Cumberland. The Corps is charged with the full water resource development of the Cumberland River Basin. This 17,900-square-mile area is located in portions of Tennessee and Kentucky. The Tennessee Valley Authority has the primary responsibility for the overall development and operations in the Tennessee River Valley. The Corps is responsible for all navigational matters in this area.

Completed so far in the Cumberland River Basin are eight multipurpose projects with reservoirs, all of which have hydroelectric power installations and four of which have navigation locks. One other multipurpose project has been impounded, but the hydroelectric power facilities are not operational to date. A "Plan of Development" for the Cumberland River Basin is available on request from the U. S. Army Engineer District, Nashville.

BACKGROUND

The Nashville District (Cumberland River Basin) has not experienced any major problems with aquatic macrophytes. The only significant aquatic plant control program that has been conducted consisted of applying 2,4-D to 150 acres of waterlilies (*Nymphaea odorata*). These areas that were treated consisted of several shallow ponds that were flooded after the impoundment of one of our reservoirs. A 10-year chemical control program that was discontinued in 1968 stabilized and controlled this infestation.

CURRENT STATUS

There are small infestations of aquatic macrophytes such as watermilfoil (*Myriophyllum* spp.), alligatorweed (*Alternanthera philoxeroides*), willowweed (*Justicia americana*), cattail (*Typha* sp.), etc., in numerous areas throughout the Cumberland River Basin. However, the majority of these affected areas remain stable and are not a problem.

Recently there has been a slight increase in the size of a few infested areas near some commercial marinas and recreational areas on one upstream storage project. No active control program has been initiated to date. Plant surveys have been taken and the affected areas are being monitored in order to determine the extent and nature of this problem.

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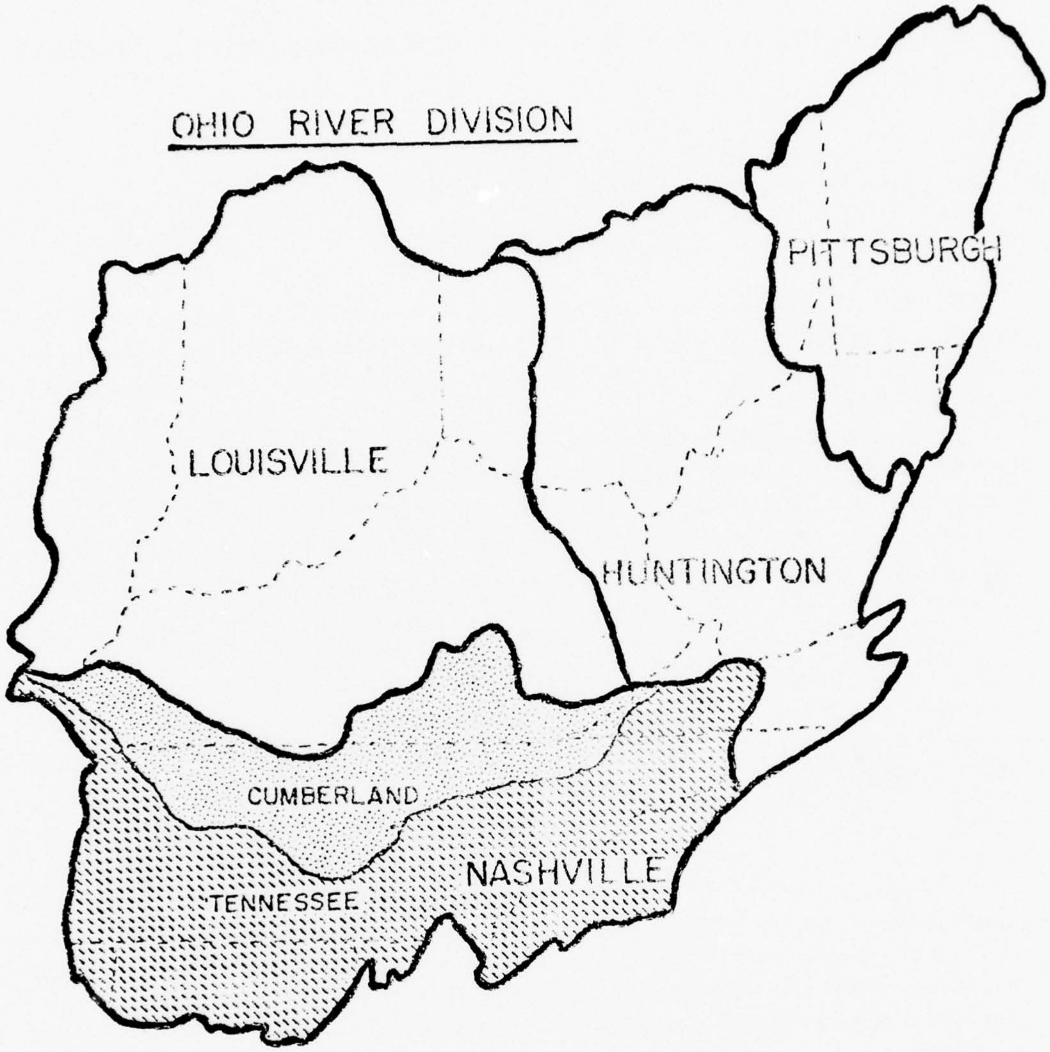

Figure 1. Four districts in the Ohio River Division

The commercial marina operators in this area fear that this increase of aquatic macrophytes will result in an economic loss to them. They are familiar with the serious problem that the Tennessee Valley Authority has encountered on some reservoirs in the Tennessee River Basin.

Although no extensive stqdy has been conducted on aquatic plant problems or reasons for the lack of problems in the Nashville District, I feel that the method of reservoir control operations (water-level fluctuations, etc.) and the terrain contribute greatly to this factor. The differences in aquatic plant problems in the two basins in the Nashville District have not, to my knowledge, been studied in detail. Perhaps this would make a worthwhile research project that would provide some useful information to all concerned.

SUMMARY

The aquatic plant control activities conducted in the Nashville District that are outlined above generally reflect the overall condition of the Ohio River Division. The Louisville, Huntington, and Pittsburgh Districts have not been required to initiate any significant aquatic plant control operations, chemical, mechanical, naturalistic, or biological. The Huntington District has experienced a minor problem with growth on the lagoons of wastewater treatment facilities.

As yet we have not had time to feel the effects of the Federal Insecticide, Fungicide, and Rodenticide Act on operator certification and licensing. Hopefully, the states will respond to the needs of the Corps and other agencies in establishing suitable certification and licensing programs for noncommercial applicators.

AQUATIC PLANTS—SOUTH ATLANTIC DIVISION

by

J. J. Raynes*

A large part of the aquatic plant problems occur in the South Atlantic Division. Most of those problems occur in the State of Florida. A brief history of the program seems to be in order at this time.

In 1896, a Mr. Crill from Palatka, Florida, petitioned Congress for help with the navigation problem created by the large masses of waterhyacinths on the St. Johns River. At that time Congress requested the Corps to investigate the problem.

As a result, in 1899, Congress authorized the removal of waterhyacinths in the navigable waters of Florida and Louisiana. It was later extended to include Alabama, Mississippi, and Texas.

The forerunner of the present Corps program, known as The Expanded Project for Aquatic Plant Control, was initiated in 1960. It was prompted by Congressional recognition that 2,4-D herbicide offered a practicable solution to combatting aquatic weeds, primarily waterhyacinths.

It was applicable to only the eight states in the Gulf and South Atlantic States; i.e. Texas, Louisiana, Mississippi, Alabama, Florida, Georgia, South Carolina, and North Carolina. The problem areas in those states are below the fall line which runs generally from south Texas, through north and central Louisiana, middle Mississippi, north central Alabama, north central Georgia, and middle South and North Carolina. In 1965 Congress revised the project to include the 50 States of the United States.

Initially, the Corps was concerned with waterhyacinths as the only problem plant. By 1960, the Corps recognized that alligatorweed was the second most important aquatic weed of concern. In 1964, considerable emphasis was given to Eurasian watermilfoil as the next problem plant that exhibited the most potential for becoming a tremendous problem. This did not materialize although it is a major problem in certain localities. Today we have a special concern for the hydrilla, which we believe can grow almost anywhere in the United States. Many in the State of Florida and elsewhere believe it represents a greater threat than even the waterhyacinth. Specific problems in the division will be discussed by representatives from the districts in our division.

We would be remiss in our total planning if we do not emphasize the point that the sole effort of our research is to provide operational results for use in field applications. Research must take into consideration restrictive regulations, objectives, and interests of other Federal and state agencies.

It is interesting to note that 10 years ago we were discussing the use of charged particles as a means of enhancing our chemical control. Now the Agriculture Department at the University of Georgia has come up with this approach. It is hoped that WES will follow this up.

We must stress the necessity for new approaches that would be most productive in leading to operational techniques that can be put into practice rather than continuing research for research's sake. Someone said we have the questions but not the answers; we would like for research to give us the answers before we are inundated by the problem.

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* U. S. Army Engineer Division, South Atlantic, Atlanta, Georgia.

AQUATIC PLANT CONTROL PROGRAM—MOBILE DISTRICT—1976

by

M. J. Eubanks*

INTRODUCTION

Although the Mobile District does not have the widespread aquatic weed problem of some of the other districts, we do feel that we have made contributions in the aquatic plant field. On July 9, 1901, it was Major William Rossell of the Mobile District who first recognized alligatorweed as a "serious obstruction to navigation and drainage in the Mobile River and its tributaries."

The Mobile District encompasses portions of six states (Louisiana, Mississippi, Alabama, Tennessee, Georgia, and Florida) containing seven major river basins (Apalachicola-Chattahoochee-Flint, Choctawhatchee-Perdido, Escambia-Conecuh, Alabama-Coosa, Black Warrior and Tombigbee, Pascagoula, and Pearl).

The most concentrated area of aquatic plant problems in the district is Lake Seminole, and the Resource Manager, Angus Gholson, will go into detail concerning this situation. Elsewhere in the southern portion of the district major problems occur, primarily in Florida and Louisiana. Water chemistry and physical characteristics of many of our streams are not conducive to troublesome aquatic plants. Other waters of our district have ideal conditions for aquatic plant growth (Table 1).

Waterhyacinths remain the major aquatic problem plants in the Mobile District, with approximately 7215 acres. Florida heads the list with 3515 acres, followed by Louisiana with 2100 acres. Lake Seminole has 800 acres (Lake Seminole acreages are not included in the state acreages); Alabama, 500 acres; Georgia, 200 acres; and Mississippi, 100 acres.

Eurasian watermilfoil is the second most prevalent problem aquatic plant (9000 acres). Lake Seminole has 8000 acres; Deer Point Reservoir (a water supply reservoir for Panama City, Florida), 700 acres; and Alabama (Mobile Delta and Millers Ferry Lake on the Alabama River), an estimated 300 acres. More surveys are needed for this plant.

Giant cutgrass is the third most prevalent; however, the only area surveyed is Lake Seminole with 4500 acres of this troublesome plant.

Hydrilla, although ranking fourth presently, shows the biggest increase over the last year. Currently, there are about 2000 acres (1000 in Lake Seminole, 1000 in Lake Jackson, and 1 in Lake Talquin, Florida).

Other problem plants include alligatorweed, waterprimrose, duckweed (*Spirodela* sp.?), *Egeria densa*, naiads, pondweeds, cabomba, coontails, bladderworts, watermilfoil, waterlilies, lotus, and watershield.

Control operations under the Operation and Maintenance program are performed at Lake Seminole, Demopolis Lake, and coastal Alabama, Mississippi, and Louisiana. Lake Seminole is not addressed in this paper, as Mr. Gholson will cover activities there.

Work on Demopolis Lake is confined to occasional mechanical clearing of boat ramps from alligatorweed mats. Spray crews from the Mobile Area Office treat waterhyacinth trouble areas mainly

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Table 1

Aquatic Plant Acreages for the Mobile District

	Waterhyacinths	Eurasian Watermilfoil	Giant Cutgrass	Hydrilla
Louisiana	2100	*	*	0
Mississippi	100**	*	*	†
Alabama	500	300**	*	†
Georgia	200**	*	*	0
Florida	3515	700	*	1001
Lake Seminole	800	8000	4500	1000
Total	7215	9000	4500+	2001

* Needs survey.
** Estimate; not surveyed.
† Reported but not confirmed.

in the Mobile Delta and occasionally in coastal Mississippi and Louisiana. Last season they treated approximately 500 acres in the Mobile Delta and about 50 acres in coastal Mississippi (Brickyard Bayou and at Pearlington) and adjacent Louisiana. Spraying is done from flat-bottom boats equipped with boomless sprayers.

Four control programs are currently carried out under the 1965 law (Cooperative Program) in the Mobile District, and two more are in the planning stage.

The cooperative program in Louisiana is between the Louisiana Wild Life and Fisheries Commission and the New Orleans District. Funding for the portion of aquatic plant control work in the Louisiana portion of our district is transferred to the New Orleans District for payment to the state. Outboard powered, flat-bottom boats with boomless sprayers is the mode of attack used in Louisiana. From July 1975 to June 1976, they reported spraying 1137 acres of waterhyacinths. At present, applicators are waiting for implementation of Louisiana's pesticide certification plan. Waterhyacinth weevil releases are planned for next growing season.

The State of Mississippi has never implemented a statewide cooperative aquatic plant control program. We are currently working with the Mississippi Marine Resources Council for a cooperative program to encompass its area of jurisdiction in coastal Mississippi. The initial target plant would be waterhyacinths with possible expansion to *Egeria* and waterprimrose problem areas. The spray crews will be expected to abide by appropriate Mississippi certification procedures. In addition, field tests with the waterhyacinth weevil are being conducted at Brickyard Bayou by the Mobile District, the Waterways Experiment Station, and the Mississippi Marine Resources Council.

Alabama also has no statewide program. Currently, we have a contract with the Jefferson County Commission that was developed for duckweed (*Spirodela* sp.?) control in the Black Warrior River and tributaries. The program is not currently active and is not expected to change. In 1975, approximately 225 acres of duckweed were sprayed with a Diquat-Cutrine Plus Invert Emulsion (EPA Experimental Permit No. 35944-EUPP-1). Also, systems were used to mechanically remove the duckweed. All results were temporary. We are currently working toward a cooperative program with Pike County in southeast Alabama for waterhyacinth control in the headwaters of the Choctawhatchee River. This

hyacinth problem stemmed from a breached dam with a pond completely covered with waterhyacinths and subsequent downstream infestation.

The statewide cooperative program for Georgia is discussed in the Savannah District report. However, we have a cooperative program with the Crisp County Power Commission for waterhyacinth control on their Lake Blackshear located on the Flint River near Cordele, Georgia. About 100 acres were treated this last growing season. An outboard powered, flat-bottom boat with a boomless sprayer was used.

Funds are transferred to the Jacksonville District for the cooperative program with the Florida Department of Natural Resources for work performed in the Mobile District's portion of the state. Airboats are normally used for spraying the hyacinths although occasionally application is by spray plane. Through August 1976, they had sprayed 2334 acres of hyacinths in the Mobile District (principally in the Apalachicola River drainage). They are also doing work on *Egeria*, *hydrilla*, cowlilies, as well as many other plants to a lesser degree. Waterhyacinth weevils and white amur research programs are being monitored. The spray crews are currently undergoing examinations for state certification.

AQUATIC PLANT PROBLEMS, LAKE SEMINOLE
U. S. ARMY CORPS OF ENGINEERS

by

A. K. Gholson, Jr.*

LAKE CHARACTERISTICS AND CLIMATE

Lake Seminole was formed by the Jim Woodruff Dam, which was designed and constructed by the U. S. Army Corps of Engineers across the Apalachicola River, northwest of Chattahoochee, Florida. The dam is located immediately below the union of the Chattahoochee and Flint Rivers, which form the two principal arms of the lake. Spring Creek and Fish Pond Drain, two secondary arms of the lake, join the Flint River approximately 6 miles above the confluence of the two rivers. The west end of the dam is located in Florida and the east end in Georgia. Approximately two thirds of Lake Seminole is in Georgia and the remaining one third in Florida. The dam was constructed primarily for navigation with the available head to be used to produce hydroelectric power. At normal pool elevation, 77.0 ft mean sea level (msl), the lake has an area of about 37,500 acres, extending about 50 miles up the Chattahoochee River and 47 miles up the Flint River. The lake has a shoreline of 250 miles. The shoreline mileage does not include the numerous islands, both large and small, located in the lake. Excepting the old river run areas, old slough and pond areas, and creek channels, a large percentage of the lake is 7.0 ft or less in depth, having extensive areas too shallow for use of flat-bottom boats propelled by 10-hp outboard motors or larger. Lake Seminole was impounded in steps or stages as features of the dam and the lock were completed. A partial impoundage was begun in March 1955. The pool was allowed to rise only to el 65.0 ft msl, which occurred during the first week of April of that year. It was then held at about that elevation until the final stage of impoundage was begun in January 1957. The lake was allowed to fill to normal top pool el 77.0 ft msl in the early part of February 1957. Being a "Run-of-the-River" type project, the pool elevation has been fairly constant, varying from about el 76.5 to 77.8 ft msl. After impoundment to el 77.0 ft msl, numerous ponds and lime sinks in the first and second bottoms (above the ordinary floodplain of the rivers) became a part of Lake Seminole. Aquatic plants common to the area were found in the ponds and lime sinks. Such plants presented little concern at the time since physical and biological forces had successfully kept them in check through the years. Impoundment upset the natural biological balance and many of the submersed, emersed, floating, and marginal aquatic plants of the ponds and lime sinks became sources of infestation for many of the shallow-water areas of the lake. The more common of these are listed as follows: waterlily, *Nymphaea odorata*; American lotus, *Nelumbo lutea*; watershield, *Brasenia schreberi*; pondweed, *Potamogeton illinoensis*; southern naiad, *Najas guadalupensis*; duckweed, *Lemna* spp.; maidencane, *Panicum hemitomon*; cowlily, *Nuphar advena*; bladderwort, *Utricularia* spp.; cattail, *Typha latifolia* and *Typha domingensis*; banana lily, *Nymphoides aquaticum*; willowweed, *Justicia americana*; chara, *Chara* spp.; primrose willow, *Ludwigia*; and smartweed, *Polygonum* spp. Extensive areas, approximately 10,000 acres, of Lake Seminole were not cleared of trees and/or brush prior to impoundment. Practically all of the inundated trees and brush were dead by 1960, and natural pruning has reduced the remaining trees to

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snags of varying height. Waterfowl and fish are attracted to these uncleared areas in great numbers. Floating-type aquatic plants lodge and flourish in parts of these uncleared areas making control from boats hazardous and difficult due to submerged stumps and tall decaying snags, leaving satisfactory control to be accomplished by aircraft. Lake Seminole is located in an area that has a mild climate, a mean temperature of about 68° F, and a long growing season that covers the period from about the middle of March through the middle of November. Although winter temperatures sometime drop below freezing for relatively short periods, they are generally not of sufficient duration to kill or seriously damage aquatic plants in the lake, in the bordering lowland and marshy areas, and in lake-affected lime sink areas, which are numerous near the lake between the Chattahoochee and Flint Rivers. Lake Seminole's favorable climate coupled with the great expanses of shallow, clear water of the Flint River, Spring Creek, and Fish Pond Drain Arms of the lake render conditions most ideal for all types of aquatic plant growth. Apparently, turbid water conditions on the Chattahoochee River Arm have restricted submersed aquatic growth somewhat in this area. However, impoundments on the Chattahoochee River above Lake Seminole and the rather sharp reduction of "row-crop" farming along this river will no doubt, through sedimentation and the reduction of suspended matter in runoff, help clear the waters of the Chattahoochee in the future, rendering them more suitable for all types of aquatic vegetation.

BRIEF HISTORY OF AQUATIC WEEDS AND CONTROL

Impoundment of Lake Seminole created a new environment with conditions ideal for the establishment and growth of all types of aquatic plant species. Problems occurred early after impoundment with hyacinth, cattails, parrotsfeather, and the pondweeds infesting 5000 to 6000 acres of the rich, clear, and shallow waters. Chemical control of the waterhyacinths during 1958 and 1959 opened the way for the phenomenal growth of alligatorweed during the early 1960's. Attempts to control alligatorweed by use of chemicals produced no satisfactory results, and this plant reached epidemic proportions in the mid-60's. A small beetle, *Agasicles hygrophila*, was introduced through the cooperative efforts of the Agricultural Research Service and the Corps of Engineers in 1967 for the control of alligatorweed. This beetle has been most successful on Lake Seminole, effectively controlling alligatorweed. Unfortunately, the drastic reduction of alligatorweed by the beetle has made reinfestation of the lake by the waterhyacinth possible. Introduced aquatic plant species have found the ideal growing conditions available in Lake Seminole most satisfactory, and several have now reached major epidemic proportions. Introduced species include Eurasian watermilfoil, *Hydrilla*, giant cutgrass, eelgrass, and *Limnophila indica*. Control measures used to date include chemical, mechanical,and biological. Some measure of success has been obtained with mechanical and chemical operations. Most satisfactory results have been obtained with biological control in the case of alligatorweed.

CURRENT AQUATIC WEED PROBLEMS

In October 1976, an estimate was made on the status, from an acreage standpoint, of the major aquatic plant weed species on or in Lake Seminole. Estimated acreages are as follows: waterhyacinths, 800 acres; Eurasian watermilfoil, 8000 acres; giant cutgrass, 4500 acres; hydrilla, 1000 acres; and alligatorweed, 50 acres. Over one third of Lake Seminole is now infested with aquatic vegetation creating serious problems from early spring until late fall. The operational and recreational purposes of

the project are threatened by the following: (1) The surface area of the lake is being reduced by many hundreds of acres due to marginal and littoral plants, particularly giant cutgrass. (2) One fourth to one third of Lake Seminole is infested with submersed aquatics rendering small boat navigation and other recreational activities in such areas practically nil during period May-November. (3) Public use of the project is being restricted by problem aquatics at public-use areas, including concessions, in small-boat channels, and in the shallow open-water areas of the lake. (4) The desired biological balance of the lake is being severely hindered by an overabundance of problem aquatics, which, among other things, interfere with the necessary predator-prey relation of fishes. (5) The public health is being placed in jeopardy by problem aquatics, which provide ideal habitats for vectors of serious communicable diseases. (6) Lake Seminole's many thousand acres of problem, or possible problem, aquatics offer a very real source of infestation of downstream areas, including the rich oyster-producing areas of Apalachicola Bay. And finally, the continued use of the nation's southernmost major man-made reservoir is in jeopardy due to problem aquatic vegetation, which presently is affecting one third of the lake's 40,000 surface water acres. The above has not but should produce serious concern within the engineering community since the problem could reduce the effective life of the project and the purpose for which the project was authorized and constructed.

CONCLUSIONS

A major resource is in trouble as a result of uncontrolled aquatic vegetation. Navigation and the production of hydroelectric power, the purposes for which the project was authorized and constructed, are threatened from two very obvious phenomena: (1) Water volume is being sacrificed to aquatic growth at an alarming rate. (2) The public's attitude toward the project and its authorized purposes, generally taken for granted, is becoming strained due to the fact that their recreational activities are becoming seriously hampered by the rapid spread and growth of aquatic vegetation. The aquatic plant problem is real, and it is serious. A solution to the problem is considered both necessary and imperative. The elimination of aquatic vegetation from the waters of Lake Seminole is not possible nor desired. Control is necessary and desired. The various tools of control, viz., mechanical, water-level manipulation, biological, chemical, and legal, are to be used prudently, economically, and in the best biological interest. Research, continued study, and observation are among the more important areas of a comprehensive AQUATIC PLANT CONTROL PROGRAM.

SELECTIVE MAINTENANCE CONTROL PLAN
ST. JOHNS RIVER, FLORIDA

by

J. C. Joyce*

INTRODUCTION

The Jacksonville District Office of the Corps of Engineers conducts waterhyacinth control operations on the St. Johns River under two separate authorizations. The Upper St. Johns, Highway 46 to the headwaters, is maintained in cooperation with the Florida Game and Fresh Water Fish Commission under the Aquatic Plant Control Program as authorized by Public Law 89-298 dated 27 October 1965. The Lower St. Johns, Highway 46 to the river's mouth at Jacksonville, contains a Federally authorized navigation project and, as such, is maintained solely by the Corps under the original operation and maintenance project for the protection of navigation, i.e. the Rivers and Harbors Act of 3 March 1899.

Throughout the history of control of the waterhyacinth on the St. Johns River, the Corps' involvement has been both extensive and turbulent. The Corps has initiated numerous mechanical and chemical control programs with varied levels of success. Recently, however, the Jacksonville District has developed a selective maintenance spray program utilizing the dimethylamine salt of 2,4-D. This plan is designed to keep the plants at the lowest level of infestation possible while scheduling operations in a manner that is consistent with environmental considerations and the public's use of the river.

OBJECTIVES OF THE PLAN

The major objectives of this plan are to:

(1) Establish a plan of operation and a definite policy that can be understood by operational personnel as well as the general public.

(2) Increase effectiveness of operations by directing treatment to areas of heaviest infestation. For instance, single plants, very small fringes, or scattered mats of plants will not normally be sprayed. Instead, these plants will be treated only when they are grouped into denser mats or fringes by wind or water currents.

(3) Reduce the total amount of herbicide required for more effective control. Analysis of the number of acres of hyacinths treated over the past 13 years indicates that there has been a sharp reduction in the amount of chemical applied since implementation of the plan. While the present level of treatment is near the values observed during the 1960's, the residual level of plants currently present, as well as adverse impacts due to the plants, is greatly reduced.

(4) Reduce environmental impacts associated with the treatment of large uncontrolled mats of plants, such as possible depletion of dissolved oxygen and damage to native vegetation and fish spawning grounds.

(5) Tailor the treatment to the environmental idiosyncrasies of plant growth and movement. On the St. Johns River, it has been determined that sections of the river exhibited varying capacity to grow

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waterhyacinths, and the air and water currents that control the movement of the plants also vary, thus treatment must be tailored to account for its variabilities.

(6) Allow for the integration of biological and mechanical control methods in those areas where they are best suited. The Jacksonville District has released *Neochetina eichhorniae* at 51 locations on the St. Johns River. The release sites were in breeder-type areas, which are seasonally inaccessible to spray operations.

(7) Increase the flexibility to schedule operations in compliance with established fish and wildlife activities and public use of the river in specified areas.

DEVELOPMENT OF THE PLAN

The developmental processes required for a control plan are basically no different than those steps that should be considered in any aquatic plant control effort. As stated earlier, this plan merely tries to more fully address environmental considerations and public-use patterns of the river. As noted in Figure 1, after the problem area is identified, the environmental situation in which operations will be conducted must be analyzed. This involves defining:

a. Existing and potential population level of aquatic plants. Experience has shown that aerial surveys are the most efficient and timely methods available to accomplish this task.

b. Morphology of water body, which will dictate the accessibility of plants to various control methods.

c. Seasonal and daily trends in streamflow and water stage. These must be analyzed in order to predict the movement and location of plants at any given point in time.

d. Likewise, seasonal and daily trends in weather conditions. They also aid in predicting movement, location and growth rate of waterhyacinth populations. Seasonal climatological information in conjuction with data on the plant's life cycle is also helpful in predicting the optimum time for and location of operational activities.

e. The location of natural and man-made obstructions, such as bridges, flood control structures, and fallen trees. These should be known in order to schedule operations such that these areas do not become jammed with plants, resulting in blockages of navigation, reduction of streamflow, or damage to the structures. Most natural obstructions, such as fallen trees, can be removed by operational personnel; also, when justified, structural modifications can be made to preclude the buildup of plants at the man-made obstructions.

f. Through the analysis of items *a* through *e*, the natural collection points. As indicated earlier, maximum operational efficiency can be obtained by scheduling treatment in these areas.

g. As previously noted, environmental constraints and use patterns, such as locations of critical fish and wildlife habitat, sensitive crops, navigation channels, and flood control works, must be known in order to set the priority and frequency of control efforts. Other aspects, such as the herbicide label restrictions and attitudes of the public, should also be considered in determining the level and method of control selected.

The next major step in the developmental process is the analysis of the resources at our disposal to manage the problem. This analysis is important in order to determine the proper mix of contracted or hired labor, types and effectiveness of control methods and equipment readily available, and amount of fiscal resources needed and available. A thorough analysis and integration of Blocks 2 and 3 (Figure 1) will determine the residual level and location of nuisance aquatic plant infestations. This will, in turn, establish the priority of control operations.

At this point in the developmental process it is possible to design a preliminary operational plan (Figure 1, Block 5), which should be coordinated with all Federal, state, and local agencies and

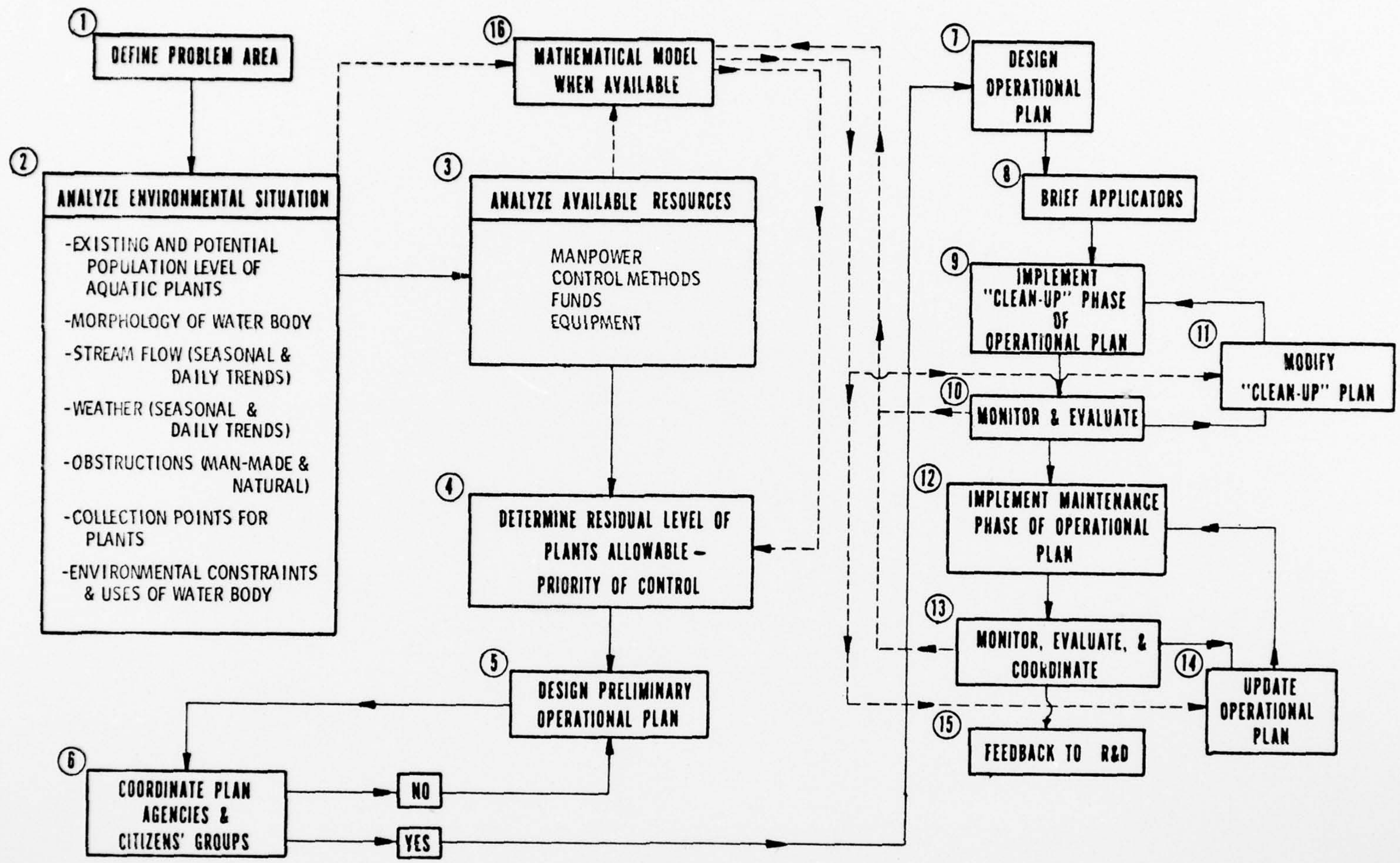

Figure 1. Aquatic Plant Control Program maintenance control flow chart

concerned citizen groups (Figure 1, Block 6). The coordination with these sources is not only important from a public relations standpoint but is also a source of input into the proper design of the operational plan.

Before initiation of the operational plan, it is necessary to brief the applicators (Figure 1, Block 8) to ensure that they thoroughly understand not only the operational aspect of the plan but also the logic and theory behind the plan. In the final analysis, the success or failure of a well-designed plan is in the hands of the applicators.

Blocks 9-14 (Figure 1) serve to indicate that there are two basic phases to a maintenance plan. The first phase is an intensive "clean up" phase designed to rapidly reduce an uncontrolled aquatic plant infestation to the desired maintenance level. Aerial applications can be most effective and are usually necessary during this phase. The second phase is the routine maintenance phase, wherein the plants are progressively treated to maintain the desired level. Both of these phases require continual monitoring, evaluation, coordination, and revision when necessary. Also, a feedback to the R&D program is necessary in order to ensure a continuous technology transfer that will aid in the dissemination of proven control methods to other operational elements and provide a data base from which even more effective control methods can be developed. Along this line, Block 16 proposes a mathematical model, which will be capable of developing and modifying operational plans through the systematic analysis of environmental data, available resources, and operational results obtained. Through this modeling effort, operational elements will be able to quickly develop more effective operational plans and respond more rapidly to changing situations associated with existing plans.

CONCLUSION

In conclusion, it is suggested that those persons responsible for the development of aquatic plant control programs analyze their area of operation according to the process described herein and determine those specific areas that would benefit from a selective maintenance control program.

RÉSUMÉ—AQUATIC PLANT CONTROL PROGRAM WILMINGTON DISTRICT

by

O. H. Johnson, Jr.*

INTRODUCTION

The purpose of this paper is to present a brief review of the Aquatic Plant Control Program in the Wilmington District and to identify known present aquatic plant problems in North Carolina. The Wilmington District became active in a small pilot-type program in 1960. The district program has been, essentially, inactive since 1974.

BACKGROUND

Alligatorweed

In the early sixties, the aquatic plant of most concern in the state was alligatorweed. It was and continues to be a pest in drainage canals, small lakes, ponds, and streams in the coastal plain area of the state. A cooperative program involving the Corps and state was developed in 1960. The Corps performed trial-type chemical control work in areas jointly agreed to by the state and Corps. Primarily, the early objective was to put to trial use chemical formulations or herbicides recommended by the then Central Advisory Research Committee.

In 1967, the first releases of the South American flea beetle for biological control were made in the state. For a number of years afterward, releases continued to be made. The beetle has, apparently, successfully overwintered. However, I understand that in the North Carolina latitudes, beetle populations do not build up in sufficient numbers until well into the growing season when alligatorweed growth has progressed to such an advanced stage that the beetles cannot make any real inroads into it before cool fall weather arrives. The end result is little or no effective control by biological means.

Seasonal chemical treatment of alligatorweed continued on a limited basis until 1974. In that year, the state became concerned over the consequences of possible environmental damages that were thought might be caused by continuing chemical applications. Even though past studies had shown no ill effects, the district was requested to restrict control measures to areas where severe navigational problems exist. There are no known problems of this extent in the state. Consequently, treatment of alligatorweed has ceased.

Eurasian Watermilfoil

In 1965, a more severe aquatic plant problem appeared in the northeastern part of the state in the large, freshwater Currituck Sound. Eurasian watermilfoil moved southward that year from the adjacent back bay area of southeastern Virginia and spread rapidly to cover probably 100,000 acres in the Currituck Sound area.

There has been considerable controversy over what to do about this weed. Some hunting and

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fishing guides favor it as beneficial while others, mainly residents and recreationists, want it removed.

On three occasions in 1968, 1971, and 1974, the Corps, with state participation, performed limited control work on watermilfoil in several areas. These were areas considered to have the highest public use and where the state desired work to be done. The 1968 work consisted of trial applications with before and after monitoring studies of effects on fish, marine organisms, chemical persistence, and the like. Granular 2,4-D was used in all milfoil treatments. The greatest acreage, about 950 acres, was treated in 1974. Environmental effects of this work were monitored by biologists of East Carolina University under a contractual study. Results have been consistently good, but the clearing provided by these "chemical mowings" lasted no more than 3 years. Regrowth from extensive adjacent untreated areas is rapid.

TODAY'S PROBLEMS

The primary aquatic plant problem in North Carolina today is certainly watermilfoil. The inconveniences and lesser problems caused by scattered alligatorweed growths are not now thought to warrant high consideration. The state held a public hearing on the watermilfoil problem in 1974 and presented a study consisting of several alternatives ranging from chemical control, mechanical control, allowing seawater to enter the sound, to simply doing nothing. In July of this year, the Federal Sea Grant Program held a meeting in the Currituck Sound area to address the problem. The meeting was lightly attended by local interests, and therein lies one of the attendant problems—lack of directed interest.

The spread and existence of watermilfoil in many acres of water in northeastern North Carolina certainly can be identified as the state's major aquatic weed problem. However, certain facts must be considered in any approach. These are:

a. There are no Corps navigational projects that are affected by milfoil growths.

b. There are no *strictly* "high use" areas that are affected, whether commercial or recreational.

c. Primarily inconvenienced are small-boat interests, recreationists, shoreline residents, and some commercial and pleasure fishermen.

d. There has been no concerted or organized effort by local interests toward developing a program; indication of local concern and interest expressed to state and Federal representatives has been negligible.

e. *What* to do for effective, practical control is undecided.

It has been my feeling that at some point in time some natural environmental control would develop to curb further spread. So far, this has not materialized. It appears that biological control might hold the greatest, if not the earliest, promise of relief. Certainly, to attempt control by chemical or mechanical means to any large extent at all presents many problems.

I expect local concern and interest will increase. Officials of the North Carolina Department of Natural and Economic Resources are well informed on the problem and are interested. However, they are presently handicapped by a lack of strong local voices regarding the milfoil. Lacking are decisions on what can and should be done, together with a lack of funding should determinations be made. These decisions must largely come from the people and the state since the waters involved are, of course, state waters. The Corps' position has been one of willing cooperation and readiness to perform limited control work where justified and desired by the state and where the state has been capable of participating in cost-sharing.

In closing, I want to mention that the Federal-State Sea Grant Program in North Carolina has

become interested in the milfoil problem in the state. As I mentioned earlier, Sea Grant sponsored an initial investigative meeting last July. If funding is approved, Sea Grant is proposing certain experimental and research activities commencing by next spring. Sea Grant's views and proposed activities are stated in its latest newsletter released last week. Limited copies are available here.

It appears that Sea Grant needs to be aware of any Corps-approved research activities. Also, research must be reemphasized in connection with the milfoil problem.

AQUATIC PLANT CONTROL IN THE SAVANNAH DISTRICT

by

K. Williams*

The Savannah District Corps of Engineers, in cooperation with the Georgia Game and Fish Commission, is in charge of the aquatic weed control program in the State of Georgia. The existing contract provides that all control work will be done by the Georgia Game and Fish Commission, with Federal reimbursement for work in excess of the 30 percent required participation. Until recently, the Savannah District has not experienced a serious aquatic weed infestation in its waterways that required control; however, infestations, primarily waterhyacinths and alligatorweed, are beginning to create problems to navigation, boating access, fishing, and other recreational pursuits. The major infestations are located in the oxbow areas and along the banks of the Satilla River from its mouth to Burnt Fork; in Jackson Lake (Georgia Power Company impoundment) located north of Macon, Georgia, on the Ocmulgee River; and in Lake Worth located near Albany, Georgia, on the Flint River.

Preparation and coordination of the Environmental Impact Statement on Aquatic Weed Control will be conducted in Fiscal Year 1977, and three areas of aquatic weed control operation are being planned for Fiscal Year 1978. There are 50 acres of waterhyacinths located in the Satilla River, 66 acres of waterhyacinths located in Lake Worth on the Flint River, and 30 acres of alligatorweed located in Jackson Lake on the Ocmulgee River. Control will be accomplished by using integrated biological and chemical controls. The chemical control to be used is 2,4-D, which will be applied by aircraft. The biological control is by the use of insects that eat the aquatic plants. Two of these, the waterhyacinth weevil, *Neochaetina* spp., and the alligatorweed flea beetle, *Agasicles*, have been released in the past in the state. The success of the waterhyacinth weevil has not been determined; however, the alligatorweed flea beetle has been reported as having had some impact on the growth of alligatorweed.

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AQUATIC PLANT CONTROL IN THE CHARLESTON DISTRICT

by

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INTRODUCTION

The major aquatic plant problems in public waters of South Carolina are caused by two exotic plants—alligatorweed (*Alternanthera philoxeroides*) and Brazilian elodea (*Egeria densa*). Alligatorweed was the first to achieve problem status, but the growth of alligatorweed has recently diminished to the extent that no spraying was deemed necessary during the 1976 growing season. Elodea is a later import whose distribution has rapidly expanded to the point that it is now the worst aquatic plant problem in the state.

SANTEE-COOPER PROJECT

The Charleston District began its cooperative aquatic plant control program in 1960 when a contract was negotiated with the South Carolina Public Service Authority (PSA) to control alligatorweed in the Santee-Cooper Project. The Santee-Cooper Project is a state hydroelectric project whose major features are Lakes Marion (about 155 square miles) and Moultrie (about 95 square miles). Under the terms of this contract, the PSA furnished the manpower and equipment; and the Federal Government furnished the herbicides, granular Silvex and dichlorophenoxyacetic acid (2,4-D), and funds up to 70 percent of the total cost. This contract was extended by supplemental agreements until its termination on 30 June 1967. This contract was allowed to terminate because of limited funds and a greater need for aquatic plant control in other waters of the state.

STATEWIDE PROJECT

Just before the termination of the contract with PSA, the district negotiated a contract with another state agency, the South Carolina Department of Agriculture, to provide for aquatic plant control in all state waters except for the Santee-Cooper Project. To date, alligatorweed has been the only target for control. Streams designated for aquatic plant control under this contract include portions of Little Pee Dee River, Black Mingo Creek, Black River, Congaree River, and the North Fork Edisto River. These stream segments comprise a total of about 166 miles of stream.

The present aquatic plant control program includes biological control, as provided by the alligatorweed flea beetle (*Agasicles* sp.) and the stem borer (*Vogtia malloi*), and when needed, the application of herbicide. These insects were released in South Carolina as the outcome of research conducted by the Agricultural Research Service of the U. S. Department of Agriculture with financial support of the Corps of Engineers. To date, the flea beetle appears to have been the more successful of the two introductions.

The only herbicide used for work under the current contract is 2,4-D in a 40 percent amine

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formulation containing not less than 4 lb of 2,4-D acid equivalent per gallon. This herbicide was formerly applied at a water-chemical mixture of 50 to 1 at an estimated rate of 8 lb of 2,4-D per acre. This rate was used because work performed on the Santee-Cooper lakes under the earlier contract indicated that application rates of less than 8 lb per acre were ineffective. However, in view of the establishment since that time of the flea beetle, any future use of 2,4-D would be done in accordance with the integrated control technique developed by the U. S. Department of Agriculture, which would involve spraying at a lower rate (2 to 4 lb per acre).

Since the district's use of 2,4-D to control alligatorweed is inconsistent with the product label, spray operations were terminated early during the 1975 spray season, and an application was made to the Environmental Protection Agency (EPA) for an exemption. A specific exemption was granted to the district in July 1976 to use 2,4-D to control alligatorweed, but no spraying was done because none of the project streams had enough alligatorweed to warrant spraying. Since the exemption granted by the EPA expires on 31 December 1976, an extension has been requested in order to provide for future spraying should alligatorweed again become a problem in public waters of the state. Although only a part of one stream was sprayed in 1975 and no spraying was done in 1976, the abundance of alligatorweed in project streams appears to be declining.

EMERGENCE OF BRAZILIAN ELODEA AS A PROBLEM

Brazilian elodea has recently become a significant problem in two large and heavily utilized water areas, and cursory observations indicate that it is now the worst aquatic plant problem in the State of South Carolina. Some of the most notable infestations are in Lake Marion, which is one of the two lakes comprising the Santee-Cooper Project. Elodea was first reported in Lake Marion in 1965 and rapidly expanded until in 1974 the area infested was on the order of 10,000 to 20,000 acres. Another major water area with a significant infestation of elodea is the upper portion of the Cooper River and its tributaries and abandoned rice fields.

The only large-scale effort to control elodea has been exerted by the PSA on Lake Marion. The PSA treated 400 acres in 1974 and 750 acres in 1975 with Ortho Diquat and planned to treat portions of the lake in 1976. The PSA found Diquat to be effective for a short period of time, but reinfestation occurred and elodea continued to spread to previously unaffected areas.

The PSA and other state and Federal agencies, including the Corps, are now involved in a cooperative effort to develop a management plan for the control of aquatic plants in the Santee-Cooper lakes. A workshop was held on 20-21 July 1976 and a second meeting is scheduled for 1 November 1976 to review a draft management plan. In the meantime, the PSA has recently requested the Charleston District to provide assistance in the control of elodea under the authority of Public Law 85-500. The district has not yet responded to this request.

TRAINING AND CERTIFICATION IN SOUTH CAROLINA

The Clemson University Cooperative Extension Service is conducting its first certification training for individuals involved in the use of pesticides in aquatic situations during the period 20-22 October 1976. Since the university stated in its announcement of this first training session that it did not know whether or when additional training in this particular category would be offered, the author, who supervises the district's aquatic plant control program, is attending this training session.

CONTROL OF WATERCHESTNUT IN NEW YORK STATE

by

S. M. Hook*

INTRODUCTION

The purpose of this paper is to describe the New York District Corps of Engineers' program to control waterchestnut (*Trapa natans*) in New York State in the Hudson and Mohawk Rivers and portions of Lake Champlain. A brief history of past control efforts is presented, after which the current program is discussed and the problems and prospects are outlined. The aquatic plant control program is authorized by Section 302 of the Rivers and Harbors Act of 1965, Public Law 89-298. This act provides for the control and eradication of obnoxious aquatic plants in navigable waters, tributary streams connecting channels, and other allied waters, in the interest of navigation, flood control, drainage, agriculture, fish and wildlife conservation, public health, and related purposes.

BACKGROUND

The waterchestnut is an annual aquatic plant native to freshwater streams and ponds of the temperate areas of southern Europe and Asia. Although the seed contains some food value and is edible, the plants are usually found in polluted waters and may be contaminated. The waterchestnut survives in mud but grows best in water depths from several inches to 5 or 6 ft. It has been found to grow in depths of up to 15 ft in New York. Its annual decomposition forms a muddy bottom of high organic content.

The plant can be identified by its waxy, floating leaves supported by swollen leaf sterns forming leaf rosettes. Each new season's growth is produced entirely from the seeds of this annual plant. The seeds germinate every spring at the beginning of May and form a cordlike stem 6 in. to 15 ft long, which reaches the surface about the middle of June or somewhat later in deeper water. The plant grows as late as October. A number of modified feathery leaves grow along the stem with a pair of branched lateral roots at the base of each of these leaves. The plant has no primary root but is weakly anchored in the bottom muds by these lateral roots. Small white flowers appear from June to early September, which develop into soft, green, horned nuts on a spongy inflated stalk. This stalk helps the leaf bladders support the rosette after the fruit is formed. Each rosette produces about 12 to 24 chestnuts. As the nut matures, the outer tissue is shed by a fermentation process and the nut becomes hard and black. Each of the four horns is sharp and has several reverse barbs. The nuts are about 20 percent heavier than water and sink when they become ripe and drop off the plant. This may occur as early as August. The plant itself is killed by frost in the fall. It is estimated that most nuts will germinate within 1 to 5 years after being dropped. Dormancies of 10 and 50 years have been reported, however. The plant spreads either by the rosettes being detached from their stems by boats to reroot in another area, or more usually by the nuts being swept by currents or waves to downstream areas.

The waterchestnut was introduced into the United States at Collins Lake near Schenectady, New York, in 1884 to "enhance" both the esthetic and fishery resources of the lake. By 1920 the waterchestnut

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had spread to the Mohawk River and by 1944 was found in the Hudson River. By this time it had also spread as far north as Lake Champlain and as far west as the Finger Lakes.

PROBLEMS ASSOCIATED WITH THE PLANT

Among the many problems caused by the waterchestnut plant are those related to various recreational activities. Because the plant has virtually closed off bays with impenetrable mats, passage has been hindered for fishing, pleasure boating, and waterfowl hunting. The waterchestnut has crowded out such desirable duck food as wild celery. It also reduces the open-water shore habitat for desirable game fish. In addition, waterchestnut provides breeding grounds for the mosquito and blackfly. Although this is not presently considered a health problem, there is an associated nuisance factor as well as an undesirable economic condition. The existence of waterchestnut can also lead to problems in the area of water supply. In a number of instances, difficulty has been experienced by this plant hindering the velocity of flow in intake systems. Potentially serious consequences might also arise for navigation, particularly lock operation. Other activities less directly affected are swimming, waterskiing, picnicking, camping, and sightseeing. Finally, the plant's fermented four-spined seed can inflict a painful wound if stepped upon and can penetrate a rubber boot.

HISTORY OF CONTROL EFFORTS

The first large-scale effort to control waterchestnut began in 1946. The New York State Conservation Department undertook this effort using (a) hand-pulling techniques in small isolated infestations, (b) underwater mowers or self-propelled barges, and (c) herbicidal sprays of the isopropyl ester of 2,4-D in fuel oil. The 2,4-D was applied by surface operated power sprayers from a fixed-wing airplane and from a helicopter. After 1948, operations were restricted to the underwater mowers, hand-pulling, and a small amount of spraying from boats. This action was taken due to claims of crop damage following aerial spraying. State control was funded under Pittman-Robertson (W-31-D) and ran until 1955, at which time it was given to the New York State Department of Conservation, Bureau of Fish, under Dingell-Johnson funding (F-13-D). Research funded by Pittman-Robertson suggested more effective methods of eradication within the framework of existing techniques. In 1965, the Bureau of Fish began a systematic eradication program, which met with initial success using the latest chemical treatment techniques. In 1969, Federal funding ceased when, in the opinion of the U. S. Fish and Wildlife Service, the benefits appeared to accrue more to the general boating public than to those engaging in hunting and fishing. Full funding for the program continued by the New York State Department of Environmental Conservation until 1970, when the Corps of Engineers contracted with the department to reimburse the state 70 percent of its eradication costs.

PRESENT PROGRAM

The approach taken by New York State has been to treat the larger dense stands chemically by use of a boat-mounted spraying unit. Smaller infestations are either hand-sprayed or hand-pulled depending on the density of the plants in the area. The herbicide 2,4-D has been found to be effective on waterchestnut at applications of 8 lb of acid equivalent (2 gal of 4-lb acid) per acre. This finding resulted from some of the earlier Dingell-Johnson work on chemical control where granular and pellet 2,4-D

were also tried under various controlled situations with little effect. 2,4-D is a restricted pesticide, and all applicators, both state and contractors, are required to be certified. The chemical is sprayed directly on the leaf surface. The effect is that of a growth hormone; the plant rapidly produces new leaf and stem cells, browns, and dies within a period of 1 to 2 weeks. Application of less than 8 lb of acid equivalent per acre acts as a growth stimulant, speeding up food production. Best results occur when the young plant is hit after the nutrients in the nut sent up the long stem are about exhausted, but before many lateral roots have been formed to take nutrients from the water.

Presently, the large infested areas requiring boat-spraying are contracted out by the state. The chemical is applied from booms that spray a fine mist on the plants at the 2-gal rate calibrated to the boat speed. The mat of plants is dampened by the boat wake and minimizes the chemical being washed off before it has had a chance to work. Hot, calm, sunny mornings with clear skies are ideal for spraying since plant metabolism is increased and drift conditions are reduced. Hand-spraying and hand-pulling are performed from canoes. The latter method, while the most tedious, is also the most effective as it is not subject to the vagaries of weather or of chemical applicator error.

Only one insect, a leaf beetle, was found to feed on waterchestnut foliage, without doing serious damage to the plants. No fungus diseases were observed. The possibility of insect or fungus control appears remote. Mechanical devices for removal cannot be ruled out for control purposes.

PROBLEMS ENCOUNTERED

The specific characteristics of the waterchestnut plant itself is central to the problem of its treatment. The prolific nature of the plant, the unpredictable delay in germination, and the relatively short growing season require a smooth operation and adequate field support.

An important area of concern is on the Vermont side of Lake Champlain Canal. Vermont has failed to treat this small infestation, which is apparently spreading in area and density. This failure jeopardizes not only New York's Champlain efforts, but also the program throughout the Hudson and Mohawk Rivers since these can be reinfested by boats transporting plants.

Since the effective spray season is relatively short, a rapid spray operation in the numerous separate infested areas is important. Some sites are easily accessible, whereas others can only be reached by water. Access to the Hudson is complicated by the railroad tracks paralleling both banks. Stage of tide, daily winds, and normal changes in weather further complicate the problem of treating all infestations in the recommended period. Drift was also considered to be a problem when some of the larger plots were sprayed by helicopter, and to a lesser degree when sprayed by boat.

Another problem is the timing and speed of application. This is prevalent particularly in the larger plots in the tidal area where water exchange apparently occurred before the chemical was fully effective. The wake created by the air boats has had a similar effect of washing the chemical off the leaves. Better kills were observed in denser, more mature stands, which appear to dampen the wake better than young stands that have just reached the surface. Lighter payloads and higher horsepower to bring the boats on plane have helped solve this problem.

A serious potential problem is the possibility that chemical treatment may not be used in effective dosages. At present the highest concentration for 2,4-D approved by EPA is for waterhyacinths at 2 lb or less per acre. Under the EPA regulation on pesticides labeling, which went into effect in 1975 (40 CFR 180), a manufacturer may apply to a state for registration for a specified use and concentration. Transvaal, the state's supplier of "Wheed-Rhap" LV-4D, an isooctyl ester of 2,4-D, did so but was

refused by the Bureau of Pesticide of the Department of Environmental Conservation. Despite the backup information presented by the Bureau of Fish on the effectiveness of the chemical at this concentration on waterchestnut, the Bureau of Pesticides was of the opinion that information on the effect of the chemical on other aquatic organisms was insufficiently detailed to support the registration and that the spirit of the law would be violated if permission to use the pesticide were granted.

ENVIRONMENTAL IMPACT

Experiments to date with 2,4-D in water have not indicated any significant detrimental effects on fish or other aquatic plants. The chemical is specific to broad-leafed plants, and care must be exercised so that drift to plants on shore does not occur. 2,4-D has a temporary effect on nontarget aquatic plants, such as spatterdock, accelerating its growth in grotesque form. It has not killed anything except in rare instances where drift occurs. Since there is no spraying within 1000 ft of intakes upstream, spray levels are low, dilution is high, and the tidal factor such that entire bays are flushed frequently, there are no deleterious effects on the rivers as a source of water supply.

RESULTS AND COSTS

A slow, but steady decline in waterchestnut infestations has resulted from the control efforts; from 2826 acres in 1966 to 1340 acres in 1976, a 53 percent reduction.

It is, nevertheless, difficult to evaluate the success of the state program on the basis of acreage figures since new areas of infestation are being discovered each year as the crews become more familiar with the rivers. Variable kills and variable regrowth the following season require virtually a site-by-site evaluation.

The most successful results have been in shallow enclosed bays where diffusion kills the plant even if the leaves are not sprayed directly. At the edge of the river or where there is much current, the leaves must be drenched more thoroughly to get a kill. This is a particular problem in the Hudson with its 4-5 ft tidal fluctuation, which results in a high-water exchange in the coves as well as in the mainstream.

Contract spraying costs in 1974 amounted to $31.60 per acre including cost of the chemical. Labor cost alone was $18.52 per acre. Hand-pulling costs were estimated at $69.27 per acre regardless of bushels pulled.

CONCLUSIONS

In order for control to be eff tive, no seed formation whatever can be permitted. The plants must be treated every year so that potent sources of infestation, which lead to a further spreading of the undesirable plant, are che ked.

A resolution of the problem of the use of the chemical 2,4-D in effective dosages is important to the continued success of the eradication effort. Additional research is called for, the focus of which should be the identification of the short- and long-term effects of 2,4-D (in the concentration called for) on the aquatic ecosystem.

The state has also begun to evaluate the use of mechanical mowers and weed cutters. The greatest problems with these removal techniques are the shallow depths and the inability to bring the equipment to some of the more inaccessible back-bay areas where chestnut is found. Tidal conditions on the

Hudson present another limit on using a weed cutter.

If no clearance is obtained for the use of the required 2,4-D by next season, the immediate response would be to shift to a complete hand-picking operation. Estimates of harvest per acre based on this year's rate range from 1 acre per man-day to 1/20 acre per man-day, depending on density.

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STATUS OF THE AQUATIC PLANT CONTROL PROGRAM IN THE NORFOLK DISTRICT, NORFOLK, VIRGINIA

by

J. D. Haluska*

On 30 June 1976, the Norfolk District concluded a 3-year study of the application of endothall and Diquat^{R} to a large probable water supply reservoir. Nuisance populations of *Egeria densa* Planchon hampered the use of the Chickahominy Reservoir (Walker Dam), Virginia, as a source of recreation and potable water.

Application of the herbicide mixture was undertaken by the Virginia Commission of Game and Inland Fisheries after the application of the same mixture in 1967 seemed to indicate that the use of these chemicals could reduce the *Egeria* populations in the reservoir.

The study of some of the 1973 applications' effects was conducted by the Department of Fisheries and Wildlife Sciences of the Virginia Polytechnic Institute and State University at Blacksburg, Virginia. The final report of this study** concluded that long-term (2-year) control of *Egeria densa* was only attained in areas of marginal *Egeria* habitat. The use of Diquat^{R} alone will probably be as effective as the endothall-Diquat^{R} mixture since the addition of the endothall was not seen to be "advantageous"; however, plant bioassay should be conducted if Diquat^{R} is used in other water areas. The mixture does not seem to be bioaccumulative and can probably be used with assurance of safety to nontarget plants and animals.

The report also noted that "replacement of the target weed with a more noxious weed is a possibility." The possible replacement species mentioned was the filamentous blue-green algae *Lyngbya*, which appeared at stations previously populated by *Egeria*.

Several final conclusions were that the reduction in submerged vegetation quantity had little impact on the biota due to incomplete macrophyte dieoff and rapid repopulation but that most anglers benefited from the reduction in submerged plant biomass.

It was recommended that subsequent applications of Diquat^{R} be used to control *Egeria* at approximately 2-year intervals and that, when appropriate, Diquat^{R} be considered for use in controlling submerged vegetation.

At present, the Norfolk District is considering the future use of Diquat^{R} in the Chickahominy Reservoir. This is the only Aquatic Plant Control project presently under active consideration in the district. Several other aquatic plant problem areas have been identified—these are Back Bay, areas of the Rappahannock River, and the Lafayette and Elizabeth Rivers. The district is also awaiting the final report of the Virginia Commission of Game and Inland Fisheries on its 3-year study of the 1973 treatment. The Norfolk District will consider these reports in determining the advisability of continued treatment of the reservoir. The resulting report should be available during Fiscal Year 1978.

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* Oceanographer, Water Resources Planning Branch, U. S. Army Engineer District, Norfolk, Virginia.

** O. E. Maughan and C. B. Shreck, "Aquatic Plant Control Using Herbicides in a Large Potable Water Supply Reservoir; Final Report for the Period July 1, 1973, to June 30, 1976," 1976, Department of Fisheries and Wildlife Sciences, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

AUTOMATED PROCESSING OF APC FIELD OPERATIONS DATA

by

J. T. McGehee*

INTRODUCTION

In order to properly monitor aquatic plant control (APC) field operations, the program manager requires detailed input from the field. These data are generally a legal requirement and essential for record purposes in the case of potential damage claims arising from the operations and for managers to evaluate the effectiveness of the overall program. For small programs this is no problem. However, with large operations, such as the Jacksonville District's, the manager soon becomes swamped with data. There are approximately 20 Florida Game and Fresh Water Fish Commission field crews and 10 Corps of Engineers crews reporting to the district. Originally, daily reports were submitted by each crew. This resulted in 900 reports each month. To cut down on the volume of reports, a weekly report form was developed. This form consolidated the information on the daily reports and lessened the volume of paper, but not the volume of data to be analyzed. The Jacksonville District Aquatic Plant Control Section worked with the district's Data Processing Center in the development of an automated processing system for the processing, display, and storage of the field data for use by program managers.

FIELD REPORTING

During a review of the information needed to document APC operations and those data required for evaluation of crew and program performance, the existing weekly report form (Figure 1) was found to be inadequate to meet these needs; thus, a new report form was needed.

In anticipation of the inherent difficulties with conversion to new methods of reporting, the general format of the old report was retained. The design of the new form was coordinated with the computer programmers and the key punch operators to make certain that the format was compatible with their normal procedures. Priority, however, was placed on simplification for the user of the form, the field crews.

The new report of operations is divided into four major sections (Figure 2): Heading, Personnel and Equipment, Time Distribution, and General. The Heading contains the pertinent identification data for sorting, retrieval, etc. The Personnel and Equipment section documents rental/wage or cost data of personnel and equipment. The Time Distribution section records distribution of the field unit's time by meaningful categories. The General section includes data on the area treated, environmental conditions, materials used for treatment, and any necessary remarks. Figure 3 is an example of a typical completed report. In practice, the reports are printed in screened blue ink so that pencil or pen will contrast and the figures will be easier for the key punch operators to see. The small numbers that accompany the Heading and Totals blocks define the fields for the key punch operators.

* Engineering Technician, Aquatic Plant Control Section, U. S. Army Engineer District, Jacksonville, Florida.

PROCESSING

The programmer constructed a computer program that processes the data and presents the cumulative summary in a format similar to the report form. The program is written in COBOL program language to be used with the district's in-house GE-225 computer. It is actually a group of programs. They are listed in the district file as "AQUATIC PROGRAMS" and carry District Program Numbers KM22 through KM29.

The first programs edit the data for missing essential data or obviously incorrect data. If these conditions exist, they are flagged on the edit output. Due to the amount of data contained in the two cards and the differences in field width, the output is presented on separate sheets for the number 1 and number 2 cards (Figures 4 and 5, respectively). This allows for uncluttered tabular review of data.

Programs KM25 and KM26 compile and print a summary of the consolidated data for the period of record fed into the computer by crew members. These data are arranged in the same general vertical order as the report of operations. Again, the printout was separated into two sheets, this time due to difficulties with data storage and getting all the information on one sheet. Figures 6 and 7 are examples of consolidated crew data for the month of June 1976. These programs, KM25 and KM26, also compile a consolidated summary of these same data by county and watershed number and present it in two printed sheets. Figures 8 and 9 are examples of the first of these two sheets for the month of June 1976.

Program KM27 consolidates the data into a presentation by agency, the Corps' hired labor forces and the state's forces that are under contract to the district (Figure 10). The average figures are the direct means computed by the total number of crews working during the period of record.

Program KM29 presents a review of the acreage of plants treated by watershed number and cost account number. One sheet is printed for each type of plant treated. Figure 11 is an example of the output for the month of June 1976 for waterhyacinths.

Simultaneously with the processing of the data, a monthly transaction tape is written. This tape contains all of the raw data from the cards. When a summary is desired for a quarter, half, or full year, these tapes can be consolidated and run for that period. This also allows for the selective retrieval of data in the future. Although a program has not been written for the retrieval, it would be a relatively simple task. We are in the process of writing other programs for the presentation of operations data by crew, watershed, county, etc., monthly for a year's period. This would enable the user to see seasonal trends or annual changes in production as effected by environmental or management conditions.

PRESENT USE OF PROGRAM

The Report of Operations is the coding form for the summary programs. The edit program catches many, but not all, errors. Experience with the use of the programs has revealed that a review of the forms prior to key punching eases the processing of the data. Questions by the key punch operators on data in the wrong blocks, blocks unfilled, etc., are minimized. Also, errors found at this time speed up the correction process. There is no need for finding the error that was flagged, mark it on the card, and have it repunched.

After the initial check, the reports are key punched, and when a month's accumulation of cards is complete, it is run on the edit program. If errors are found by the edit program, the printout is returned to the APC Section for correction. If no errors are flagged, the summary programs are run. Each month's summary reports are then reviewed by district managers of the APC program for

determinations of how well the field operations are progressing. Copies of the monthly summaries are sent to the state contractor and district field offices for their use in managing their operations.

The new reporting procedure has been in effect for approximately 2 years. We now find that the past printouts are quite valuable for use in estimating inventories of herbicides, productive time to be expected during a certain time of year in a specific water body, and display of other information previously unavailable to us.

PLANS FOR THE FUTURE

During the formulation of the new reporting and processing procedures, provisions were made for expansion of the use of the program. The watershed numbers were made excessively large for a purpose. Each of the watershed designations is one thousand or greater by even thousands. Later, the watersheds will be divided into significant sections by a numeric designation in the tens or hundreds place of the watershed number. Further subdivision is available by numeric assignment of the units place. Although the district is only treating waterhyacinths at this time, provision has been made for reporting operations on other aquatic plants. A numeral 1 in the "Kind of Vegetation" box in the Heading of the Report of Operations signifies operations on waterhyacinths. As other plants are added to the program, number assignments will give specific printouts for the new plants.

The storage of operations reports has been a space- and time-consuming chore. Retrieval of information from these reports and consolidation of these data are likewise very time-consuming and costly. With the new system, all the data from the reports are stored in raw form on magnetic tape. We have not exercised the option yet, but these data are easily accessible by use of a simple search, sort, and print program. The retrieved data can also be consolidated for printout under the existing summary programs or printed as reconstructions of the original report forms.

The decision-making process for the scheduling of aquatic plant treatment operations is very involved. Developments over the past few years have further complicated the process, and indications are that further complications are on the way. Modern managers are learning more and more to rely on systems models to assist in the decision-making process as the factors affecting the decisions become more complex. The APC managers in the Jacksonville District believe in this philosophy. The whole reporting and data processing system presented here was designed and constructed as a minor feedback subsystem. Ultimately, in addition to its monitoring function, we envision this subsystem as a data base for use in a much larger mathematical model of our operations, a model that would enable us to test management options using real-world data to get indications of the probable results. Costly and time-consuming mistakes and assumptions could thereby be minimized, and the benefits to be derived from limited resources maximized.

WEEKLY LOG
OBNOXICUS AQUATIC PLANT CONTROL AND ERADICATION OPERATIONS
CORPS OF ENGINEERS, JACKSONVILLE, FLORIDA DISTRICT
CHEMICAL TREATMENT

Field Office ______________________ Date __________ Thru __________ 196__
Location ______________________
Watershed ______________________ County ______________________

Kind of vegetation: Hyacinth ( ) Alligatorweed ( ) Other __________
Height of vegetation: 0 to 12" tall ( ) 12" to 24" tall ( ) 24" up ( )

Item / Date	Mon.	Tues.	Wed.	Thurs.	Fri.	Totals
Plant						
Vehicle & mileage						
Effective spray time						
Travel Time: Plant						
Travel Time: Vehicle						
Lay time, weather						
Lay time, other						
Crew Time, Name & Hours a.						
b.						
Chemicals & Wetting Agent a.						
b.						
Strength of mixture						
Area Treated Yds. Wide by Miles Long						
Acres sprayed						
Current: Direction & Speed						
Wind: Direction & Velocity						
Weather						
Temp. Air						
Temp. Water						
Condition of stream						

Remarks:

Submitted ______________________
Hyacinth Plant Operator

Approved ______________________
Supervisor

SAJ Form 454
26 May 61

Figure 1. Weekly report form of APC operations

WEEKLY REPORT OF OPERATIONS
AQUATIC PLANT CONTROL

Crew No. 1 (1 - 5) Period (6 - 9) thru (10 - 13) 19 (14,15)

Watershed and Area (16 - 20) County (21,22)

Cost Account No. (23 - 27) - (28 - 32) - (33 - 37) Kind of vegetation (38)

ITEM		Sun	Mon	Tue	Wed	Thu	Fri	Sat	TOTALS	
Equip. Rental	Airboat									[illegible]
	Aircraft									40
	Kickerboat									41
	Other (days)									42
Vehicle (Start) Mileage (End)										
Crew Time (Hrs)										
Per diem Name & Amount										
									Hr. Min.	
Time Distribution	Effective spray time									16
	Travel time vehicle									20
	Travel time plant									24
	Lost time rain									28
	Lost time wind									[illegible]
	Minor repairs (explain)									36
	Major repairs (explain)									40
	Other duties									44
	Holiday or leave									48
	Survey									52
	Preparation									56
	Removing obstructions									60
	Miscellaneous (explain)									64
	Total time in period									68
Herbicide & Amount (gals.)	2,4-D amine									72
	Other (specify)									75
Diluent & Conc.										
Acres sprayed										78
Wind Data	Time									
	Direction									
	Velocity									

Sun	Mon	Tue	Wed	Thu	Fri	Sat

Remarks

Submitted: ______________________ Approved: ______________________
Crew Chief

SAJ Form 454
1 Jun 73

Figure 2. Revised weekly report form of APC operations

WEEKLY REPORT OF OPERATIONS
AQUATIC PLANT CONTROL

Crew No. 10017 (1-5) Period 0601 (6-9) thru 0605 (10-13) 1976 (14,15)

Watershed and Area St. Johns River 01000 (16-20) County Putnam 22 (21,22)

Cost Account No. CDRAG (23-27) 33200 (28-32) - 05400 (33-37) Kind of vegetation 1 (38)

ITEM		Sun	Mon	Tue 1	Wed 2	Thu 3	Fri 4	Sat 5	TOTALS	
Equip. Rental: Airboat	#15			1	1	1	1		4	39
Equip. Rental: Aircraft										40
Equip. Rental: Kickerboat										41
Equip. Rental: Other (days)										42
Vehicle	CE8935			84					84	
Mileage	CE8937				87	87	87		261	
Crew	T. Smith			800	800	800	800		3200	
	T. Jones			800	800	800	800		3200	
Per diem										
									hr. min.	
Time Distribution: Effective spray time				4:30	3:00	4:30	3:00		1500	16
Travel time vehicle				2:00	2:00	2:00	2:00		800	20
Travel time plant				30	30	30	30		200	24
Lost time rain					1:30		2:00		330	28
Lost time wind						30			30	32
Minor repairs (explain)										36
Major repairs (explain)										40
Other duties										44
Holiday or leave										48
Survey										52
Preparation				1:00	1:00	30	30		300	56
Removing obstructions										60
Miscellaneous (explain)										64
Total time in period				8:00	8:00	8:00	8:00		3200	68
Herbicide & Amount (gals.)	2,4-D amine			8	6	8	6		28	72
	Other (specify)									75
Diluent & Conc.	Water			1:200	1:200	1:200	1:200			
Acres sprayed				16	12	16	12		56	78
Wind Data	Time									
	Direction									
	Velocity									

Sun	Mon	Tue	Wed	Thu	Fri	Sat
	Holiday	Orange Lake	Orange Lake	Orange Lake	Orange Lake	

Remarks

Submitted: T. Smith
Crew Chief

Approved: L. Moore

SAJ Form 454
1 Jun 73

Figure 3. Typical completed report form of APC operations

```
31 JUN 76                U S ARMY ENGINEER DISTRICT, JACKSONVILLE                     PROGRAM KM22
                             EDIT AQUATIC PLANT CONTROL CARDS

0B0000B00B00B11B11B11B11112B22B222222223333333B3B3B4B4B4B444B444B4555B555B5556B6666B6666B6777
1 2345 67 89 01 23 45 67890 12 3456789012345б7 8 9 0 1 2 345 678 9012 3456 7890 1234 5678 9012

1     1 06-01 06-05 76 18000 60 CDRAG3320005600 1 2            115 3200 3200
1     1 06-07 06-12 76 18000 60 CDRAG3320005600 1 5            263 4000 4000
1     1 06-13 06-19 76 18000 60 CDRAG3320005600 1 3            164 3200 4000
1     1 06-20 06-26 76 18000 60 CDRAG3320005600 1 5            324 4000 3200  800
1     1 06-27 06-28 76 18000 60 CDRAG3320005600 1 1             60  800  800
1     1 06-29 06-30 76  7000 27 CDRAG3320005600 1 2            283 1600 1600

1     2 06-01 06-05 76 18000 60 CDRAG3320005600 1 4            208 3200 3200
1     2 06-06 06-12 76 18000 60 CDRAG3320005600 1 5            285 4000 4000
1     2 06-13 06-19 76 18000 60 CDRAG3320005600 1 5            375 4000 4000
1     2 06-20 06-25 76 18000 60 CDRAG3320005600 1 5            332 4000 4000

1     3 06-01 06-05 76 18000 60 CDRAG3320005500 1 4            160 3200 1600 1600
1     3 06-06 06-12 76 18000 60 CDRAG3320005600 1 4            160 3200 3200
1     3 06-13 06-19 76 18000 60 CDRAG3320005600 1 5            234 4000 4000
1     3 06-29 06-30 76  7000 27 CDRAG3320005500 1 2            269 1600 1600

1     4 06-01 06-05 76 18000 49 CDRAG3320005600 1        2     124 1600 1600
1     4 06-06 06-12 76 18000 60 CDRAG3320005600 1      2 1     142 4000  800 2400
1     4 06-13 06-19 76 18000 60 CDRAG3320005600 1      5       349 4000 4000
1     4 06-20 06-26 76 18000 49 CDRAG3320005600 1      3 2     253 4000 4000 2400
1     4 06-27 06-30 76 18000 60 CDRAG3320005600 1      3       220 2400 2400

1     9 06-01 06-05 76  1000 17 CDRAG3320005400 1 4            389 3200 3200          4    4
1     9 06-06 06-12 76  1000 17 CDRAG3320005400 1 5            282 4000 4000          5    5
1     9 06-13 06-19 76  1000  8 CDRAG3320005400 1 5            171 4000 4000          5    5
1     9 06-20 06-26 76  1000  8 CDRAG3320005400 1 5            145 4000 4000          5    5
1     9 06-27 06-30 76  1000  8 CDRAG3320005400 1 3            122 2400 2400          3    3

1    10 06-01 06-05 76  1000 22 CDRAG3320005400 1                  3200 3200          5    5
1    10 06-06 06-12 76  1000 22 CDRAG3320005400 1              919 4000 4000          6    6
1    10 06-13 06-17 76  1000 22 CDRAG3320005400 1 4            165 3200 3200
1    10 06-18 06-19 76  1000 20 CDRAG3320005400 1 1             50  800  800
1    10 06-20 06-26 76  1000 22 CDRAG3320005400 1 4            190 3600       4000
1    10 06-27 06-30 76  1000 48 CDRAG3320005400 1 1             90 1600  800

1    14 06-01 06-05 76  1000 22 CDRAG3320005400 1                       2800
```

Figure 4. Program KM22—card no. 1 of the edit output

```
31 JUN 76                    U S ARMY ENGINEER DISTRICT, JACKSONVILLE                    PROGRAM KM22
                                EDIT AQUATIC PLANT CONTROL CARDS

0B0000B00B00 11B11B11B1111B22222222B2233B3333B3333B4444B4444B4455B5555B5555B6666B6666B6677B777B777B778
1 2345 67 89 01 23 45 6789 01234567 8901 2345 6789 0123 4567 8901 2345 6789 0123 4567 8901 234 567 890

2    1 06-01 06-05 76 1100 300 100                 1600       800       100           4000  24      60
2    1 06-07 06-12 76 2230 730 230   200   30                           230  230      4000  52     130
2    1 06-13 06-19 76 1130 430 130   100  130  800            300       130  230      4000  24      60
2    1 06-20 06-26 76 2530 830 230   100                                230           4000  52     130
2    1 06-27 06-28 76  530 130  30                                       30            800  12      30
2    1 06-29 06-30 76 1000 500                                          100           1600  24      60

2    2 06-01 06-05 76 1800 600 200   130       150            800       300           4000  40     100
2    2 06-06 06-12 76 2400 730 230   300                                300           4000  52     130
2    2 06-13 06-19 76 1830 900 300   130  100                           300  400      4000  40     100
2    2 06-20 06-26 76 2400 830 230   200                                300           4000  52     130

2    3 06-01 06-05 76 2200 400       100  100  100            800       300           4000  56     140
2    3 06-06 06-12 76 1630 400 100   400  200   30            800       400           4000  40     100
2    3 06-13 06-19 76 2500 700  30        200   30                      500           4000  60     150
2    3 06-29 06-30 76  630 700            100                       30  100           1600  16      40

2    4 06-01 06-05 76  800 300       130       150                      200           1600  15      30
2    4 06-06 06-12 76 1200 400       300  100  900       800            300           4000  22      52
2    4 06-13 06-19 76 2330 830       130  130                           500           4000  58     145
2    4 06-20 06-26 76 2500 600       330                                530           4000  57     132
2    4 06-27 06-30 76 1530 630                  30                      130           2400  36      90

2    9 06-01 06-05 76 1430 900 200   230        30                      230        100 3200  21      42
2    9 06-06 06-12 76 2030 500 200   700  200   30                      300           4000  31      62
2    9 06-13 06-19 76 1930 500 200   300  630   30                      300         30 4000  24      48
2    9 06-20 06-26 76 2400 400  30   300  300  150                      330         30 4000  38      76
2    9 06-27 06-30 76 1530 230 230   130                                200           2400  28      56

2   10 06-01 06-05 76                                                            3200 3200
2   10 06-06 06-12 76                                                            4000 4000
2   10 06-13 06-17 76  930 200 700   300  630                           200        200 3200  19      38
2   10 06-18 06-19 76  300 100 300                                       30         30  800   6      12
2   10 06-20 06-26 76  200 500 200   900        30            400       100  600 1030 4000   4       8
2   10 06-27 06-30 76  500 130       100                     1500        30           2400  10      20

2   14 06-01 06-05 76                                        3200                     3200
```

Figure 5. Program KM22—card no. 2 of the edit output

31 JUN 76 U S ARMY ENGINEER DISTRICT, JACKSONVILLE PROGRAM KM25

SUMMARY BY CREW NUMBER

CREW NUMBER	1	2	3	4	9	10	14	12	18	19
AIRBOAT RENTAL	18	19	15		22	10	8	18	21	6
AIRCRAFT RENTAL										1
KICKERBOAT RENTAL				13						
RENTAL OTHER				5						
VEHICLE MILEAGE	1209	1200	873	1098	1109	1404	489	1416	657	605
							160		225	
CREW TIME A	168.00	152.00	120.00	160.00	176.00	164.00	80.00	136.00	176.00	168.00
CREW TIME B	168.00	152.00	104.00	128.00	176.00	120.00	92.00	88.00	176.00	136.00
CREW TIME C	3.00		16.00	48.00		40.00		8.00		
TOTAL MAN HOURS	344.00	304.00	240.00	336.00	352.00	324.00	172.00	232.00	352.00	304.00
PER DIEM A					22	11			22	11
PER DIEM B					22	11			22	11
PER DIEM C										
TOTAL PER DIEM					44	22			44	22
2,4-D AMINE	188	184	172	186	142	39	62	122	163	34
OTHER CHEMICALS										
ACRES SPRAYED	470	460	430	449	284	78	124	244	326	68

Figure 6. Program KM25—summary of data by crew number

31 JUN 76 U S ARMY ENGINEER DISTRICT, JACKSONVILLE PROGRAM KM26

SUMMARY BY CREW NUMBER

CREW NUMBER	1	2	3	4	9	10	14	15	18	19
EFFECTIVE TIME	86.00	84.30	70.00	84.00	94.00	19.30	31.00	63.00	83.00	18.00
TRAVEL TIME VEHICLE	30.00	31.00	22.00	28.00	25.30	9.30	16.00	36.00	25.30	14.00
TRAVEL TIME PLANT	8.00	10.00	1.30		9.00	12.00	4.00	7.00	5.00	2.30
LOST TIME WIND	2.00	1.00	6.00	2.30	11.30	6.30	7.00	15.00	18.30	2.30
LOST TIME RAIN	4.00	8.00	5.00	9.30	17.00	13.00		11.30	13.00	14.30
MINOR REPAIRS	3.00	1.30	2.00	11.00	3.00	.30	2.00			.30
MAJOR REPAIRS	16.00								9.30	
OTHER DUTIES				8.00					.30	
HOLIDAY OR LEAVE	16.00	8.00	16.00			20.00	104.00	32.00		48.00
SURVEY			.30							
PREPARATION	9.00	12.00	13.00	17.00	14.00	4.00	4.00	10.00	12.30	4.00
REM OBSTRUCTIONS	5.00	4.00				5.00			2.00	
MISCELLANEOUS					2.00	85.00	8.00	1.30	6.30	72.00
TOTAL TIME	184.00	160.00	136.00	160.00	176.00	176.00	176.00	176.00	176.00	176.00
% EFFECTIVE TIME	46.74	52.81	51.47	52.50	53.41	11.08	17.61	35.79	47.16	10.23
% LOST TIME	53.26	47.19	48.53	47.50	46.59	88.92	82.39	64.20	52.84	89.77
ACRES PER HOUR	5.46	5.44	6.14	5.34	3.02	4.00	4.00	3.87	3.93	3.78

Figure 7. Program KM26—summary of data by crew number

31 JUN 76 U S ARMY ENGINEER DISTRICT, JACKSONVILLE PROGRAM KM25

SUMMARY BY WATERSHED NUMBER

WATERSHED NUMBER	1000	2000	3000	6000	7000	8000	9000	16000	18000	27101	27106
AIRBOAT RENTAL	103	55	54	8	4	58	30	29	48	2	8
AIRCRAFT RENTAL	1		18								
KICKERBOAT RENTAL									13		
RENTAL OTHER									5		
VEHICLE MILEAGE	7021	2990	2814		552	5214	765	1229	3628	267	879
	385	2510	1960	1262			1763				196
CREW TIME A	1044.00	460.00	496.00	64.00	32.00	466.30	240.00	262.00	568.00	16.00	83.30
CREW TIME B	892.00	432.00	497.00	64.00	32.00	416.00	264.00	238.00	520.00	16.00	83.30
CREW TIME C	88.00	200.00	120.00						72.00		
TOTAL MAN HOURS	2024.00	1092.00	1113.00	128.00	64.00	882.30	504.00	500.00	1160.00	32.00	167.00
PER DIEM A	1816	19000	30725	2000		14250	1750	5750		2975	4000
PER DIEM B	1066	12250	18400	2000		12250	2500	500		2975	4000
PER DIEM C	7500	5000	6000								
TOTAL PER DIEM	10382	36250	55125	4000		26500	4250	6250		5950	8000
2,4-D AMINE	639	461	2484	20	40	452	105	218	692	12	9
OTHER CHEMICALS	25			4		5					
ACRES SPRAYED	1303	938	2673	72	100	906	210	436	1709	24	18

Figure 8. Program KM25—summary of data by watershed number

31 JUN 76			U S ARMY ENGINEER DISTRICT, JACKSONVILLE									PROGRAM KM25
					SUMMARY BY COUNTY NUMBER							
COUNTY NUMBER	3	5	7	8	11	15	17	20	22	26	27	28
AIRBOAT RENTAL	6	1	14	25	49	2	26	1	8	25	4	13
AIRCRAFT RENTAL					1					18		
KICKERBOAT RENTAL												
RENTAL OTHER		93	1080	841	4179		1570	50	1274	1491	552	648
VEHICLE MILEAGE	852	9	140	225	160	410				1507		891
CREW TIME A	48.00	16.00	112.00	208.00	408.00	16.00	208.00	8.00	252.00	336.00	32.00	108.00
CREW TIME B	48.00	16.00	72.00	208.00	344.00	16.00	200.00	8.00	204.00	281.00	32.00	104.00
CREW TIME C			48.00		8.00				40.00	40.00		
TOTAL MAN HOURS	96.00	32.00	232.00	416.00	760.00	32.00	408.00	16.00	496.00	657.00	64.00	212.00
PER DIEM A	1500	250	2500	26	1500	500	268		22	26725		3250
PER DIEM B	1500	250	1750	26	3500	500	18		22	9400		3250
PER DIEM C			9000							4250		
TOTAL PER DIEM	3000	500	13250	52	5000	1000	286		44	40375		6500
2,4-D AMINE	14	12	85	181	280	6	144	6	23	2274	40	85
OTHER CHEMICALS	4		25									
ACRES SPRAYED	60	24	201	362	560	12	288	12	46	2443	100	170

Figure 9. Program KM25 – summary of data by county number

31 JUN 76 U S ARMY ENGINEER DISTRICT, JACKSONVILLE PROGRAM KM27

MONTHLY SUMMARY AQUATIC PLANT CONTROL

SUMMARY BY AGENCY

ITEM	GC TOTALS	GC AVERAGES	COE TOTALS	COE AVERAGES	GRAND TOTALS	OVERALL AVERAGES
AIRBOAT RENTAL	262	12	137	13	399	12
AIRCRAFT RENTAL	18		1		19	
KICKERBOAT RENTAL			13	1	13	
OTHER RENTAL			5		5	
VEHICLE MILEAGE	15499	738	10060	1006	25559	924
	7719	367	385	38	8104	261
CREW TIME A	2232.00	106.25	1500.00	150.00	3732.00	120.38
CREW TIME B	2114.30	101.00	1340.00	134.00	3454.30	111.42
CREW TIME C	360.00	17.14	120.00	12.00	480.00	15.48
TOTAL MAN HOURS	4706.30	224.10	2960.00	296.00	7666.30	247.28
PER DIEM A	82200	3914	66	6	82266	2653
PER DIEM B	55875	2660	66	6	55941	1804
PER DIEM C	18500	880			18500	596
TOTAL PER DIEM	156575	7455	132	13	156707	5055
EFFECTIVE TIME	518.00	25.06	633.00	63.30	1151.00	37.12
TRAVEL TIME VEHICLE	564.00	27.25	237.30	24.13	801.30	26.24
TRAVEL TIME PLANT	50.45	2.40	59.00	6.30	109.45	3.53
LOST TIME RAIN	152.00	7.23	95.30	9.53	247.30	8.37
LOST TIME WIND	180.00	8.57	72.30	7.23	252.30	8.13
MINOR REPAIRS	192.00	9.14	28.30	3.23	220.30	7.10
MAJOR REPAIRS	70.00	3.33	25.30	2.53	95.30	3.07
OTHER DUTIES	88.00	4.19	9.30	1.23	96.30	3.10
HOLIDAY AND LEAVE	42.00	2.00	244.00	24.40	286.00	9.22
SURVEY	180.30	8.58	.30	.03	181.00	6.23
PREPARATION	179.15	8.53	99.30	10.33	278.45	9.38
REM OBSTRUCTIONS	112.30	5.34	17.00	2.10	129.30	4.17
MISCELLANEOUS	89.00	4.23	175.00	17.50	264.00	8.51
TOTAL ACRES	5656	269	2933	293	8589	277

Figure 10. Program KM27—summary by agency of APC operations, June 1976

31 JUN 76 — U S ARMY ENGINEER DISTRICT, JACKSONVILLE — PROGRAM KM29

ACREAGE SUMMARY

WATER HYACINTH

WATERSHED NUMBER	COE RAG	COE APC	COE CFB	COE OTHER	GC APC	TOTAL
01000 ST. JOHNS	1124				179	1303
02000 WITHLACOOCHEE					938	938
03000 KISSIMMEE					2873	2873
06000 ALAFIA MANATEE					72	72
07000 ISTOKPOGA	100					100
08000 SUWANNEE					905	906
09000 PEACE					210	210
16000 APALACHICOLA				436		436
18000 CALOOSAHATCHEE	1709					1709
BGA01 OTHER					24	24
BGA06 OTHER					18	16
TOTAL	2933			436	5220	8589

Figure 11. Program KM29—acreage summary of waterhyacinths treated, June 1976

THE PROJECTED IMPACT OF WATERHYACINTH INFESTATION IN TEXAS

by

A. R. Benton, Jr.*

INTRODUCTION

The author has just completed a successful research project whose central objective was the development of an economical remote sensing system for the detection and monitoring of aquatic plant infestations.[1] Because it was considered inappropriate to view the technical problem apart from the aquatic plant problem itself, the study also looked into such things as the history of the various species in this country: their introduction, their spread, their resistance to control measures, and their economic impact.

Of particular interest was the phenomenon of waterhyacinth evapotranspiration. Sin Texas is well along on a major program of surface water development, and since many of the state's large new reservoirs have increasing levels of waterhyacinth infestation, the problem of total evapotranspiration losses in Texas seemed wort!. looking into.

What was needed first was an approximation of the level of infestation that might be expected in Texas. Next, it was necessary to determine what the resultant water losses might be from an infestation of that magnitude. This paper describes how the approximations were carried out and shows the results.

BASIS FOR TREND ESTIMATION IN TEXAS

There are a large number of factors that the various states have in common with respect to the spread or control of aquatic weeds. These include:

- the relative effectiveness of ongoing control programs,
- the high nutrient levels currently inherent in most watersheds,
- the close relationship between reservoir construction and spread of infestation, and, perhaps related to the increase in reservoir construction,
- the ubiquitous trailered boat, quite probably the most efficient spread mechanism of all.

Conversely, there are many factors that would account for significant differences in outbreak occurrence, spread rates, and control effectiveness. These include:

- differences in climate, e.g., southern Florida's semitropical climate permits waterhyacinth to behave as a perennial, spreading throughout the calendar year if unchecked, while Texas' is less benign and results in winter senescence for the plant,
- economic constraints, e.g., Florida has seen fit to make a $15,000,000 per year commitment for plant control,[2] while the Texas level of effort is less than 2 percent of that figure.[3]
- legislative constraints that limit the effectiveness of biological control efforts, e.g., Texas' law prohibiting introduction of the white amur into state waters, and
- historical differences, e.g., much of the spread of waterhyacinth in Florida occurred prior to the

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discovery of the effectiveness of 2,4-D, while, conversely, Texas' problems with waterhyacinth paralleled the advent of trailered boats.

Keeping these factors in mind, it is plausible to make a series of comparisons, with respect to given species, between the growth habitat of Texas and that of a state having a longer history of infestation.

EXAMINATION OF WATERHYACINTH COVERAGE TRENDS IN OTHER AREAS

Florida seems an appropriate locale against which to compare and project the level of waterhyacinth infestation in Texas. While Louisiana as a whole is more similar to southeast Texas in climate, its infested waters are for the most part lowland bayous rather than lakes or reservoirs. Further, the literature concerning the Louisiana situation is scant and also indicative of order of magnitude guesses on plant coverage. Florida, with its many natural and man-made lakes, its high level of recreational boating activity, and the relatively cool and seasonal climate found in its northern half, is not all that unlike east and southeast Texas. Florida seems also to keep somewhat better track of the spread of waterhyacinth than other states.

The reporting of hyacinth spread over the years has been interesting. Those who take the trouble of making a reasonably accurate survey of plant coverage are usually the agencies having the responsibility for hyacinth control, i.e., the Florida Department of Natural Resources (or its precursors) and the U. S. Army Corps of Engineers. It seems obligatory for these agencies, in the course of giving the current coverage figures, to indicate that they actually represent an *improvement* over the condition that existed a short time previous.

Thus we find a 1962 report by Tabita and Woods[4] quoting a 1947 Corps of Engineers survey, which discovered 25,000 ha (62,000 acres) at that time. They went on to estimate that the 1961 coverage was 32,000 ha (80,000 acres), which, they indicated, represented an improvement resulting from the Corps' maintenance program.

Blakey[5] stated that good progress in hyacinth control had been made in Florida by the Corps of Engineers, resulting in a remaining infestation in 1965 of "less than" 40,000 ha (100,000 acres). Timmer and Weldon,[6] reporting the 1966 condition in Florida, stated that 36,000 ha (90,000 acres) of waterhyacinth still remained after decades of intensive control operations.

Burkhalter[2] estimates the current hyacinth coverage at 120,000 ha (300,000 acres), down from 160,000 ha (400,000 acres) several years previous. He also indicates that the coverage figure now seems stable.

The results of these fairly steady improvements since 1947 are shown in Figure 1, plotted in terms of hectares and in terms of percent coverage based on Florida's 1,000,000 ha (2,500,000 acres) of fresh water. The individual data points are circled. A best-fit exponential curve is shown as a solid line. The equation of the curve is

$$y = 1.016 \left(e^{0.9513x} - 1\right)$$

where y = coverage in thousands of hectares and x = year 1890 (the initial date of infestation in Florida waters).

Figure 1 indicates that progress in hyacinth eradication in Florida may not be as rapid as might be hoped for, even with many millions of dollars being spent annually for control. It is also seen that

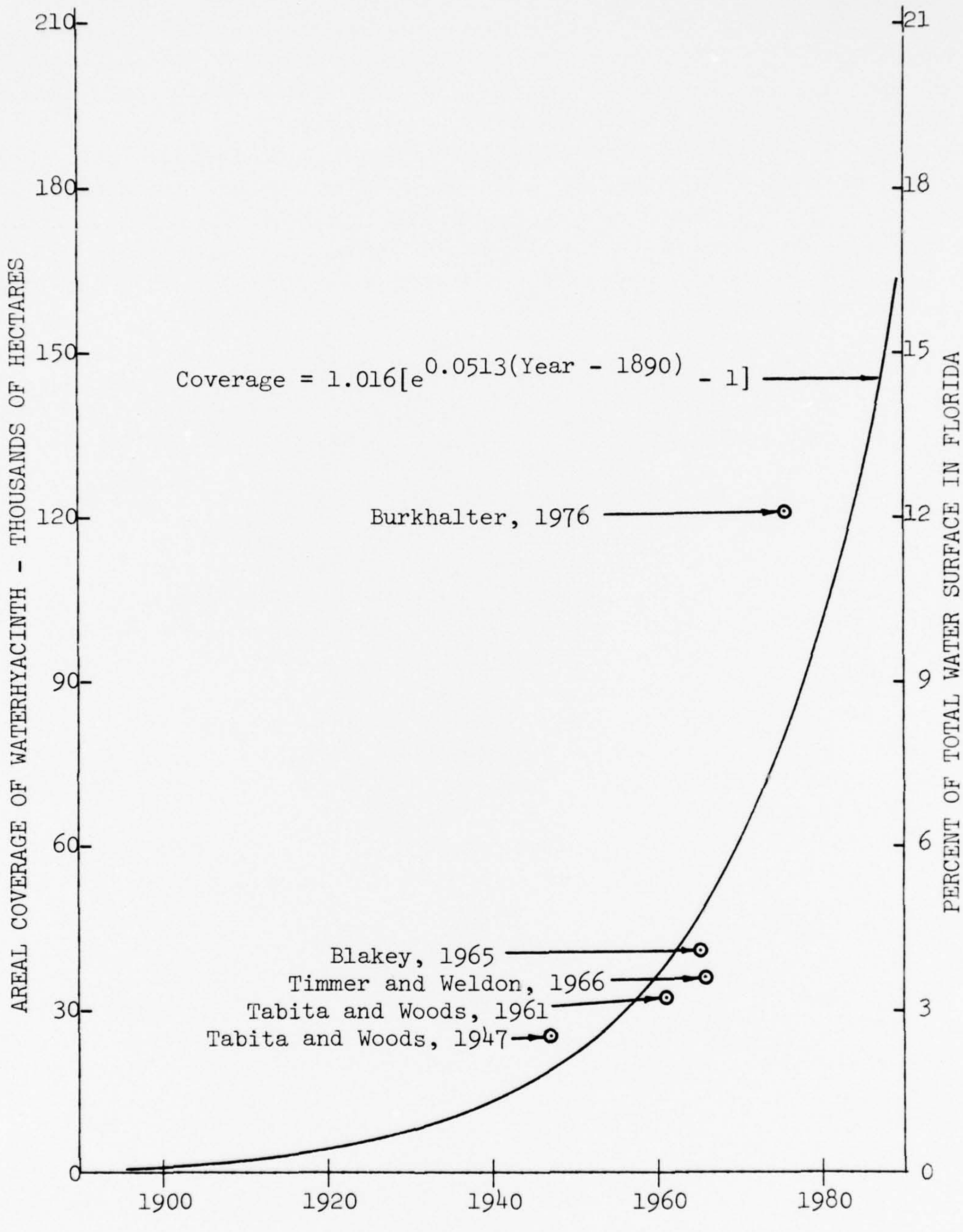

Figure 1. Trend of waterhyacinth coverage in Florida

hyacinth coverage in Florida has not reached a stable plateau. Quite the contrary, it would appear that coverage will reach 15 percent or more in the near future. Barring a future breakthrough in control methodology, the slope of the exponential curve in Figure 1 indicates that if a stable coverage is reached in Florida, it would probably be at the level of not less than 20 percent.

Most of Florida's lakes are natural water bodies. An exception is Rodman Reservoir in central Florida, a climatological area subjected to frosts of about the same frequency and severity as the southern half of the Texas coastal plain. Rodman Reservoir was first filled in 1970, at which time waterhyacinth was first noted. By August of 1971, there was a 10 percent coverage of waterhyacinth. By October of 1974, despite concerted control efforts, the coverage of waterhyacinth had increased to 25 percent. It is of particular interest that the greatest spread occurred in 1974, following a winter having killing frosts.[7]

The Rodman Reservoir experience indicates that southeast Texas, with its rapidly increasing number of reservoirs and lack of natural lakes, could quite probably experience mid- to long-term coverage of waterhyacinth of at least the same magnitude as that anticipated for Florida, about 20 percent.

In addition, the Rodman Reservoir figures also indicate a quicker spread than that encountered in natural waters. This is borne out by the experience to date in Texas reservoirs. This may be the result of the exceptionally high nutrient concentrations in the major watersheds of both states.

The presumption of 20 percent coverage on Texas reservoirs is not unreasonable, particularly considering the fact that the magnitude of the control effort in Texas is substantially below that of Florida from the standpoint of total dollars, although on the basis of cost per hectare of waterhyacinth coverage it is more nearly equivalent.

A somewhat lower level of control effort is presumed to be currently under way in Mexico, where a great number of new irrigation reservoirs have recently been completed and a rapid spread of waterhyacinth has subsequently occurred. Table 1 shows the latest hyacinth coverage in a number of fairly new reservoirs.[8]

Omitting the two large reservoirs having very rece[illegible]tions, waterhyacinth coverage amounts to 5,450 ha on 15,210 ha of water surface, or a composite total of 36 percent. This substantial coverage occurs despite a modest mechanical and chemical control effort.[8]

The Mexican experience is probably a good example of what might happen in Texas if the control effort fails to grow at least in proportion to cumulative reservoir surface area.

With respect to waterhyacinth, it will be assumed that coverage on Texas lakes will reach somewhat between 20 and 36 percent; the lower figure if the current level of effectiveness and level of effort per hectare is maintained, the higher figure if coverage increases without a commensurate increase in control effort or effectiveness.

TRANSPIRATION LOSSES RESULTING FROM WATERHYACINTH INFESTATIONS

The arguments made in favor of aquatic plant control are usually centered on the plants' impact on recreation, navigation, land values, public health, water quality, and aesthetics. These are all legitimate issues but difficult ones to quantify. There does not seem to be a direct relationship between plant-infested area, or percentage of total area infested, and specific economic or social losses resulting from the factors listed above.

Table 1
Waterhyacinth Coverage on Reservoirs in Mexico

Reservoir	Area ha	Waterhyacinth ha	Coverage %
Lago de Chapalo	15,000	300	2*
Lago Chatitlan	2,200	200	9
Presa Solis	4,900	2500	51
Presa Yuriria	3,300	400	12
Presa Rusario	1,380	550	40
Lago de Patzcuaro	10,000	400	4*
Presa Ibarra	270	60	22
Presa Endho	1,300	780	60
Presa Avila Comancho	1,800	900	50
Presa Capatizio	60	60	100
Totals	40,210	6150	15
Totals, less (*)	15,210	5450	36

* New infestations.

It is difficult to equate a 5 percent plant infestation on a given lake with a 5 percent reduction in, for example, recreational activity. However, a 100 percent coverage of aquatic plants would certainly constitute a 100 percent loss of recreational usage. Since loss of recreational value is cited perhaps more than any other factor when discussing the impact of aquatic weed infestation, it has often had dollar values assigned to it.

Federal and state agencies having the responsibility for aquatic plant control find it necessary to substantiate budget increases by raising the specter of potential dollar losses if plant spread is unchecked. These hypothetical losses are then called "benefits" that would accrue if a given level of budgetary increase for control were authorized. One must, of course, postulate that the requested budget increase would result in subsequent control, heading off the projected economic losses.

For example, the U. S. Army Corps of Engineers[9] estimated that $194,000 in annual benefits would accrue from "eradication" of aquatic plants in certain lakes in east and southeast Texas. Eradication costs were estimated at $29,000 per year, providing a hypothetical benefit:cost ratio of 6.7:1. Of the $194,000 in benefits, $142,800 was to be the result of "restored recreational activities." Of that amount, $74,800 was to have come from Lake Corpus Christi alone. The analysis assumed that without control efforts the lake would become 100 percent infested by 1975; the $74,800 was therefore the assumed total loss in recreational value. In the case of the remainder of the infested lakes in Texas, the Corps developed its benefit figures by multiplying the acreage of current infestation by the number of visitor-days per acre per year. That result was in turn multiplied by an assumed benefit of $1 per visitor day. This formula provides a constant benefit per acre eradicated.

Although the Corps-recommended eradication program has been put into effect, the spread of aquatic plants is now greater than it was in 1968 when the Corps' survey was made.[3,10] In addition, the cost of control efforts has risen ten-fold,[3] an amount which considerably exceeds the 1971-1976 inflation rate. This indicates, among other things, that the problem is far more serious than it was considered to be

at the time the benefit:cost calculation was made.

Given the hindsight available now, it is easy enough to question yesterday's benefit:cost analysis; however, one cannot ignore the necessity for it. Any new course of action requires the belief that more good than bad will accrue therefrom. In the case of a person or group seeking funds to inaugurate a new or expanded program, somewhere along the line someone must be convinced that it will be an advantageous thing to do. This is true whether the potential doer is the U. S. Army Corps of Engineers, the Florida Department of Natural Resources, or the Texas Parks and Wildlife Department.

The Corps' figures on loss of recreational potential may or may not be correct. This author feels that the important consideration in the case of reservoirs or canals is the water itself, not a secondary use of it. For this reason, it might now be useful to consider the amount of water that will be lost from its intended use in Texas if adequate aquatic plant control efforts are not made.

The State of Texas is now proceeding to carry out the objectives of an ambitious program to increase the amount of water available for municipal and industrial supply, for irrigation, and for flow maintenance in the estuaries.[11] The question to be answered is, "To what extent will the basic water supply expectations not be met because of the unanticipated impact of aquatic plants?"

The word "unanticipated" is important here. The 1968 Texas Water Plan[11] discusses the loss of stored water from evaporation and seepage. The plan also contains a brief passage on "control of water-wasting vegetation." This section, however, deals exclusively with phreatophytes (woody plants whose roots penetrate the saturated zones in groundwater aquifers and adjacent to streams) and with brush species that transpire water from the broad expanses of upper watersheds. Nowhere in the plan is there mention of water losses due to aquatic plants. It is quite possible that aquatic plants did not begin to represent a major problem in Texas until after the bulk of the plan had been written.

There are at least two major mechanisms for aquatic-plant-caused water loss: tran iration losses in reservoirs and losses in canals resulting from flow retardance. The former effect has the greater relevance to hyacinth infestations.

Basis for Projection

The phenomenon of plant transpiration is reasonably well known and the 1968 Texas Water Plan discusses transpiration losses from phreatophytes. Of even greater significance is the potential loss of water from transpiration of floating aquatic plants in reservoirs. The only widespread floating plant of importance in the United States today is waterhyacinth. Several researchers in the United States have investigated transpiration rates of mature waterhyacinth. Their results are expressed in terms of the ratio of plant transpiration to open-water evaporation per unit area. The highest figure, 5.3, was obtained by Rogers and Davis.[12] Timmer and Weldon,[6] in Florida, found a ratio of 3.7, while Penfound and Earle,[13] in Louisiana, obtained 3.2. The Rogers and Davis experiment utilized periodic harvesting to reduce crowding, while the latter two groups left the plants in the crowded state usually found in nature.

Timmer and Weldon also took data on assumed causative factors, such as temperature, relative humidity, wind speed, and solar radiation. They found little direct correlation of transpiration with temperature, humidity, or air movement. They did, however, discover a strong correlation between solar radiation and transpiration, a relationship that held almost constant over the late April-to-early September time frame of the experiment. There were 11 weeklong measurements taken during the 18-week period of the test. The mean average weekly transpiration rate was found to be 10.06 cm (3.96 in.), and the mean cumulative solar radiation per week was 3505 Langley's. This equates to 2.870 cm (1.130

in.) of transpiration per thousand Langley's.

The same experiment showed that there was not a constant relationship between transpiration and evaporation. Although the Timmer and Weldon mean value was 3.7, the ratio varied between 13.4:1 and 2.2:1. For this reason, it does not seem appropriate to use the 3.7 figure as a factor for determining transpiration at a different place or time. It does seem reasonable, however, to use their derived relationship between solar radiation and transpiration as a predictive factor in Texas.

Using this relationship, the climatological records for Texas, and the anticipated waterhyacinth coverages for Texas lakes derived earlier, a reasonable projection of anticipated water losses may be computed for the particular areas in Texas where waterhyacinth infestation problems occur.

Areas Under Consideration

Waterhyacinth is a semitropical plant. As such, it occurs within a limited geographic area in the United States. It cannot tolerate extremely cold or protracted winters. The plant does well throughout Florida, whose climate is dominated by maritime influence. The Gulf Coast area, from the Florida panhandle through south Texas, being also maritime in climate, is rarely subjected to lengthly intrusions of winter continental air masses. This situation holds for some distance inland from the immediate coastal zone.

The Corps of Engineers, in its design memorandum for aquatic plant control in Texas,[9] stated that waterhyacinth occurs in Texas to about 320 km (200 miles) inland. The author has selected an area of assumed hyacinth coverage, which conforms roughly to the Corps' stated 320-km range. For convenience, this area includes all of the Sulphur, Cypress, Sabine, Neches, San Jacinto, and Lavaca watersheds. It also includes that portion of the Trinity, Brazos, Colorado, Guadalupe, San Antonio, and Nueces watersheds that lie below the 150-m (500-ft) elevation. Thus, the area of interest includes all relatively low-lying areas in east and southeast Texas. It also includes all of the reservoirs that will contribute significantly to the Coastal Canal system of the Texas Water Plan.[11]

There may be reservoirs within this area which, for one reason or another, would not be faced with a particularly high level of hyacinth infestation. Conversely, there are undoubtedly reservoirs lying inland from this area, particularly in south Texas, which will achieve significant levels of infestation. For the purpose of this study, however, it will be assumed that all reservoirs within the chosen area will potentially reach the 20 percent infestation level developed earlier.

Determination of Net Transpiration

The length of the growing season for waterhyacinth in Texas appears to vary from year to year. The plant has not been widespread in this state long enough for reliable figures to have become established. The author has observed heavy infestations of healthy hyacinth in Lake Livingston as early as mid-April of 1974 and as late as mid-December of 1974 and 1975. Because the winter of 1974-1975 was unusually cold, heavy spring growth did not occur in Lake Livingston until late June. The norm would appear to be mid-May. For the purpose of this report, it is assumed that the period of heavy infestation in Texas extends from June through November, inclusive.

Climatological tables exist that provide long-term monthly averages of both solar radiation and evaporation for the various subregions within the State of Texas.[14] Average monthly cumulative solar radiation values for June through November have been abstracted for each of the river basins and summed in Table 2. Similarly, the June-through-November mean monthly cumulative evaporation values[15] have been added together and are also listed in Table 2.

Table 2
Net Transpiration in Texas, June Through November

Watershed	Solar Radiation Langley's × 10^3	Transpiration metres (ft)	Evaporation metres (ft)	Net Transpiration metres (ft)	Ratio of Transpiration to Evaporation
Sulphur	83.59	2.40 (7.87)	0.80 (2.61)	1.60 (5.26)	3.02
Cypress	83.35	2.39 (7.85)	0.74 (2.44)	1.65 (5.41)	3.22
Sabine	82.42	2.37 (7.76)	0.70 (2.29)	1.67 (5.47)	3.39
Neches	84.21	2.42 (7.93)	0.70 (2.29)	1.72 (5.64)	3.46
Trinity	86.04	2.47 (8.10)	0.80 (2.64)	1.67 (5.46)	3.07
San Jacinto	86.45	2.48 (8.14)	0.81 (2.67)	1.67 (5.47)	3.05
Brazos	86.77	2.49 (8.17)	0.92 (3.02)	1.57 (5.15)	2.71
Colorado	87.52	2.51 (8.24)	0.91 (2.97)	1.60 (5.27)	2.77
Lavaca	87.73	2.52 (8.26)	0.87 (2.84)	1.65 (5.42)	2.91
Guadalupe	88.41	2.54 (8.32)	0.97 (3.19)	1.57 (5.13)	2.61
San Antonio	89.26	2.56 (8.40)	0.95 (3.13)	1.61 (5.27)	2.68
Nueces	89.57	2.57 (8.43)	1.10 (3.52)	1.47 (4.91)	2.39

Cumulative radiation in thousands of Langley's appears in the second column of Table 2. The Timmer and Weldon[6] value of 2.870 cm (1.130 in.) of transpiration per thousand Langley's has been multiplied by the solar radiation values in the second column to obtain June-through-November transpiration. This is expressed in both metres and feet in the third column of Table 2. Kane's evaporation totals for that period[15] are shown in the fourth column in both metres and feet.

The fifth column lists the differences between transpiration and evaporation. This is the net loss of water in a hyacinth-covered area during the June-through-November period, by watershed.

The final column in Table 2 lists the ratios of transpiration to evaporation for a unit area of reservoir surface. Note that the average ratio of the three watersheds adjacent to the Louisiana border closely approximates the value of 3.2, which Penfound and Earle[13] obtained for Louisiana.

Anticipated Loss in Water Volume

Given the Table 2 values for annual net transpiration, the surface area of the reservoirs of interest, and the 20 percent potential hyacinth coverage assumed for all reservoirs, the annual water loss may be calculated for each reservoir by multiplying the three values together.

Table 3
Expected Water Loss in the Trinity River Watershed

Reservoir	Surface Area hectares (acres)	Jun-Nov Hyacinth Coverage hectares (acres)	Jun-Nov Net Transpiration metres (ft)	Jun-Nov Water Loss ha-metres (acre-ft)	Planned Annual Yield ha-metres (acre-ft)	Water Loss as Percent	
						Yield	Normal Evaporation
Cedar Creek	13,660 (33,750)	2,730 (6,750)	1.67 (5.46)	4,550 (36,900)	24,100 (195,000)	19	41
Houston County	520 (1,280)	100 (260)	1.67 (5.46)	170 (1,400)	900 (7,000)	20	41
Livingston	33,430 (82,600)	6,690 (16,520)	1.67 (5.46)	11,130 (90,200)	167,000 (1,354,000)	16	41
Tennessee Colony	48,360 (119,500)	9,670 (23,900)	1.67 (5.46)	16,100 (130,500)			
Richland Creek	15,720 (38,850)	3,140 (7,770)	1.67 (5.46)	5,230 (42,400)	24,700 200,000*	21	41
Tehuacana Creek	7,690 (19,000)	1,540 (3,800)	1.67 (5.46)	2,550 (20,700)	12,300 100,000*	21	41
Bedias	11,100 (27,400)	2,220 (5,480)	1.67 (5.46)	3,690 (29,900)	12,800 (104,000)	29	41
Wallisville	7,970 (19,700)	1,590 (3,940)	1.67 (5.46)	2,650 (21,500)	11,100 (90,000)	24	41
Anahuac	2,140 (5,300)	430 (1,060)	1.67 (5.46)	720 (5,800)	4,300 (35,000)	17	41
Totals	140,590 (347,380)	28,120 (69,480)	1.67 (5.46)	46,790 (379,300)	257,200 (2,085,000)	18	41

* Estimated.

Table 3 shows these figures for a fairly typical Texas watershed. The first column lists the reservoirs, both existing and planned. The second column lists reservoir surface areas taken from the latest revisions to the Texas Water Plan.[11] The third column figures show anticipated hyacinth coverage, equal to 20 percent of the surface area. Column four contains the assumed average net annual transpiration of hyacinth-covered areas, taken from Table 2. The fifth column lists the transpiration loss volumes for each reservoir, the product of the values from the two previous columns. Column six lists the annual yield from each reservoir according to the Texas Water Plan. The seventh column shows the annual transpiration loss from each reservoir expressed as percentage of planned annual yield. The final column shows annual transpiration loss from each reservoir as percentage of normal anticipated evaporation. The bottom line shows the watershed totals for reservoir surface area, plant coverage area, water loss, and planned yield and the average percentage water losses for the watershed.

The Texas Water Plan anticipates that each watershed will be developed to achieve maximum yield. Losses through evapotranspiration from hyacinth-infested reservoirs will therefore not ordinarily be recoverable.

The percentage water loss for watersheds tends to be higher in the south than in the northeast. This is because average streamflow per unit area of watershed is greater and evaporation is less in northeast and east Texas than in south Texas. This allows greater sustained yield per unit volume in the average

east Texas reservoir, and thus, higher yield in proportion to transpiration losses.

The Lake Corpus Christi Water Loss Study

A recent joint study by the Texas Water Development Board and the U. S. Geological Survey[16] delved into the unaccounted water loss of 61,300 ha-m (497,000 acre-ft) from Lake Corpus Christi during the period January 1958 to September 1965. Lacking sufficient data with which to substantiate or refute its conclusions, the investigators attributed 95 percent of the loss to percolation into the local aquifer, the Goliad Sands.

Without stating how the figure was obtained, the report estimated that unmeasured evapotranspiration might account for the loss of 2,200 ha-m (18,000 acre-ft) during the first 4 years of the 8-year study period.

Guerra[17] states that waterhyacinth was introduced in Lake Corpus Christi in 1930 and by 1970 had expanded to cover 3,200 ha (8,000 acres), about 50 percent of the lake's surface area at that time. Assuming a mean waterhyacinth coverage of 2,400 ha (6,000 acres) during the period January 1958 to September 1965, a transpiration loss of 29,000 ha-m (236,000 acre-ft) can be readily calculated using the net transpiration value from Table 2. This amounts to roughly half of the unaccounted loss and makes it easier to justify loss of the balance through percolation into the Goliad Sands.

Total Losses in East and Southeast Texas

We now have significantly greater information concerning the water loss potential of aquatic plants than was available during the writing of the Texas Water Plan[11] or of the report on Lake Corpus Christi.[16] In future years the water loss phenomenon will cease to be a localized or infrequent curiosity in the State of Texas. It will instead be a major problem that should be carefully evaluated in the course of planning for optimum use of the flow in the watersheds of east and southeast Texas.

Table 4 summarizes the bottom line figures for all the watersheds listed in Table 2. The bottom line of Table 4, in turn, indicates the total water losses that may be anticipated when the average level of waterhyacinth spread reaches the not unlikely level of 20 percent, as it seems sure to do in Florida. The total for all watersheds is 256,000 ha-m (2,075,000 acre-ft) per year, or 19.5 percent of the planned yield of all of the reservoirs in the areas under consideration.

Economic Impact in Texas

The costs of water in a given reservoir or reservoir site vary with the cost of construction, the net amount of water that may be diverted from downstream flow, and the operation and maintenance costs involved in water storage, diversion, and delivery.

The primary customer for the surface water in Lake Livingston is the city of Houston. An ongoing study of Houston's water requirements assumes that Lake Livingston water can be delivered to the city for $584 per ha-m ($72 per acre-ft).[18] Since roughly half of the construction and operation costs involves the distribution system, the value of water in the reservoir is closer to half the cost indicated above.

Rough estimates by the Bureau of Reclamation indicate that the cost of water from Choke Canyon Reservoir will be about $340 per ha-m ($42 per acre-ft) and that Cibolo Reservoir water will cost close to $810 per ha-m ($100 per acre-ft). Choke Canyon water requires no delivery system. The water will simply be held in the reservoir for delivery down the Nueces River to Corpus Christi Lake and subsequent delivery through the existing Corpus Christi distribution system.[19]

Table 4
Cumulative Annual Water Loss from Waterhyacinth—East and Southeast Texas

Watershed	Surface Area hectares (acres)	Hyacinth Coverage hectares (acres)	Net Transpiration metres (ft)	Water Loss ha-metres (acre-ft)	Planned Yield ha-metres (acre-ft)	Water Loss as Percent: Yield	Water Loss as Percent: Normal Evaporation
Sulphur River	124,820 (308,440)	24,960 (61,690)	1.60 (5.26)	40,010 (324,400)	174,900 (1,418,000)	23.0	40.0
Cypress Creek	38,550 (95,260)	7,710 (19,150)	1.65 (5.41)	12,700 (103,000)	83,600 (678,000)	15.0	44.0
Sabine River	126,740 (313,180)	25,350 (62,640)	1.67 (5.47)	42,300 (342,900)	332,700 (2,697,000)	13.0	48.0
Neches River	148,460 (366,860)	29,690 (73,370)	1.72 (5.64)	51,050 (413,900)	278,600 (2,259,000)	18.0	49.0
Trinity River	140,590 (347,380)	28,160 (69,480)	1.67 (5.47)	46,790 (379,300)	257,200 (2,085,000)	18.0	41.0
San Jacinto River	14,140 (34,930)	2,830 (6,990)	1.67 (5.47)	4,720 (38,300)	21,500 (174,000)	22.0	41.0
Brazos River	59,840 (147,880)	11,970 (29,580)	1.57 (5.15)	18,790 (152,300)	51,400 (417,000)	37.0	34.0
Colorado River	16,150 (39,900)	3,230 (7,980)	1.60 (5.27)	5,190 (42,100)	15,200 (123,000)	34.0	35.0
Lavaca River	7,470 (18,470)	1,490 (3,690)	1.65 (5.42)	2,470 (20,000)	13,000 (105,000)	19.0	38.0
Guadalupe River	51,360 (125,920)	10,270 (25,380)	1.57 (5.13)	16,060 (130,200)	30,600 (248,000)	53.0	32.0
San Antonio River	27,620 (68,250)	5,420 (13,650)	1.61 (5.27)	8,870 (71,900)	21,600 (175,000)	41.0	34.0
Nueces River	18,510 (45,740)	3,700 (9,150)	1.47 (4.91)	5,540 (44,900)	27,400 (222,000)	20.0	18.0
Totals	774,270 (1,913,210)	154,850 (382,640)	– –	254,490 (2,063,200)	1,307,700 (10,601,000)	19.5	41.6

It would appear that $325 per ha-m ($40 per acre-ft) is a reasonable value for currently developed surface water in east and southeast Texas. This being the case, the previously cited 256,000 ha-m (2,075,000 acre-ft) of annual water loss in that part of the state would be valued at $83,000,000 per year in 1976 dollars.

This is a very substantial loss resulting from aquatic weeds, far more, certainly, than what might be attributable to loss in recreational value.

With this magnitude of loss involved, it would certainly pay to invest a rather considerable amount in an effective aquatic control program for Texas. If, for example, a resulting 50 percent decrease in aquatic plant coverage might be presumed, control program funding at the level of 20 percent of the maximum loss figure would prove a bargain. Thus, a $17,000,000 per year control program would bring about benefits on the order of over $40,000,000 per year.

It is the author's contention that a control program of this relative size, inclusive of a concurrent remote sensing monitoring capability, would make a 50 percent reduction in infestation quite feasible.

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THE LARGE-SCALE OPERATIONS MANAGEMENT TEST (LSOMT) WITH THE WHITE AMUR AT LAKE CONWAY, ORLANDO, FLORIDA

by

R. F. Theriot*

BACKGROUND

Historically, most aquatic weeds have been controlled by chemical and mechanical means. Recently, however, there has been a push to develop the capability for using various biological agents for control of certain problem aquatic plant species. The major impetus behind this push is the concern regarding detrimental effects to the environment because of prolonged chemical use in areas of chronic aquatic weed problems. Also, the spiraling cost of chemicals and energy needed to conduct chemical and mechanical aquatic weed control programs has become prohibitive. It is generally thought that biological controls will be more economical and more compatible with the environment in which they are placed.

Early biological control research involved the use of insects for control of alligatorweed and, more recently, of waterhyacinths. Subsequent research has involved plant pathogens and herbivorous fishes.

A herbivorous fish from China, the white amur, has received considerable attention because of its ability to consume large amounts of submergent vegetation. With the alarming spread of hydrilla and Eurasian watermilfoil in the last decade, research has been escalated to determine if indeed the white amur can be utilized as an aquatic weed control, too.

It should be realized that the question is not whether or not some number of white amur per acre will control most species of submersed vegetation. This question has already been answered. The question is whether or not we can control the vegetation at some acceptable level and at the same time cause as few detrimental effects in the existing environment as possible as compared with other existing methods of control, i.e. chemical and mechanical.

The U. S. Army Engineer Waterways Experiment Station (WES) has designed a large-scale field test on Lake Conway, Florida, to determine the feasibility of using the white amur as an agent for the control and management of hydrilla.

In viewing the white amur as a possible operational tool to control aquatic plants, we find that not enough is known on which to base an assessment of the effects of the fish on various components of the system. The system responses, along with stated desired long-term effects, predict such aspects as stocking rates, stocking sizes, optimum time for stocking, and intervals for restocking, if necessary. To determine these critical rates and times, it is necessary first to answer several basic questions. For example, what is the effect of the white amur on hydrilla, and how do we measure the effect? What is the effect of the white amur on the ecology of the lake—water quality, game fish, zooplankton, and phytoplankton, etc.? What happens to the white amur with time—growth, mortality, food habits, etc.? What waters are amenable to plant control using the white amur?

To answer these questions, we have contracts with the University of Florida, the Florida Game and Fresh Water Fish Commission (FG&FWFC), the Orange County Pollution Control Department, and

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the Florida Department of Natural Resources to collect the data on the Lake Conway project. It is recognized that the empirical data collected will not in itself provide a sufficient picture of the dynamics of the ecosystem to allow prediction of the effectiveness or effects of introducing the white amur. For this reason, we are contracting for a performing in-house, extensive modeling. This effort will provide the necessary vehicle to incorporate the data and provide us with a predictive capability in using the fish.

In addition to other data now being collected, we are also writing a statement of work to request proposals to collect data on reptiles and amphibians, as this work unit was inadvertently omitted from a previous contract.

TEST SITE

Constraints on Selection

In accordance with the field operational orientation of the LSOMT, selection of a test site was constrained by only two qualifying criteria. First, the test site had to be relatively large, so as to be reasonably in scale with the operational requirements of the sites in which the target plant species exists as a general problem; otherwise, it could be of any size, shape, or location consistent with feasible use of the white amur. Second, the test site had to constitute a definable, relatively closed ecosystem, such that the inflows and outflows could be reasonably established and controlled, if required by local, state, or Federal regulations.

Selection of Lake Conway

Lake Conway, along with a number of other systems, met these criteria. Lake Conway was ultimately chosen because of the relative ease with which the system could be made secure, owing to the small number and size of inflows and outflows and stability of water level, which fluctuates only 2 to 3 ft annually.

For those of you who are not familiar with the project site, it is composed of Lake Gatlin, the two pools of Little Lake Conway, and the two pools of Lake Conway (Figure 1). These five pools, comprising 1820 acres, make up the test site for the large-scale field test with the white amur.

Security of the Site

To protect the integrity of the study site and prevent the escape of a viable fish population from it, three fish barriers will be erected, two in Lake Conway and one in Lake Mare Prairie (Figure 2).

Structure 1 (Figure 3), the main concern, is an outlet consisting of three concrete culverts under Daetwyler Drive. Fish escaping at this location could easily travel to Lake Mare Prairie down Boggy Creek to the Lower Lakes Region and ultimately to Lake Okeechobee. For this reason, structure 3 on Lake Mare Prairie would serve as a secondary barrier along this route. To protect the fish barrier erected at structure 1, a debris barrier was built immediately in front (Figure 3).

Structure 2 (Figure 4) is a rectangular concrete culvert under the Seaboard Coast Line Railroad near the corner of Orange Avenue and Jamaica Street in Orlando. This culvert is in a small canal that carries overflow from Lake Jessamine into Little Lake Conway.

Structure 3 (Figure 5) is the outlet control structure for the Lake Mare Prairie and the secondary barrier to structure 1.

We are at the present time negotiating for construction of these barriers.

As an additional precaution for maintaining a viable fish population, the WES contracted with the

Figure 1. Test site, Lake Conway complex

Figure 2. Location of barrier structures

Figure 3. Culverts (structure 1) under Daetwyler Drive

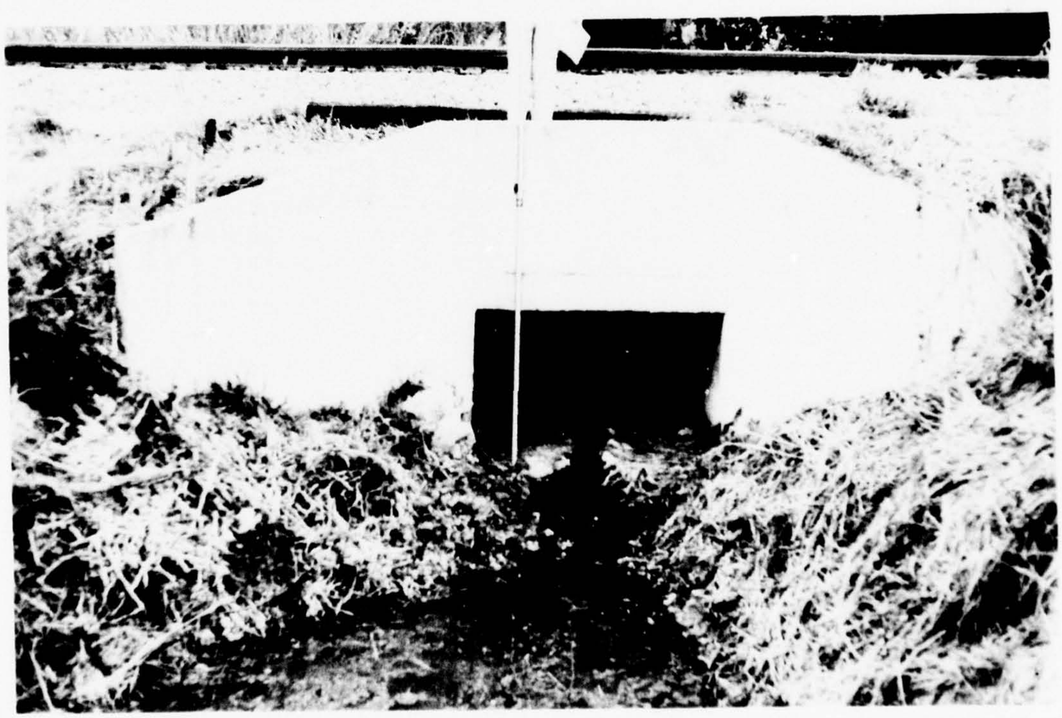

Figure 4. Culvert (structure 2) outflow from Lake Jessamine

Figure 5. Outlet control structure (structure 3) for Lake Mare Prairie viewed from upstream

USDI Fish Farming Experimental Station at Stuttgart, Arkansas, to produce a monosex fish population. The Fish Farming Experimental Station is at the present time growing the fish that will be used in the Lake Conway project to control the aquatic weeds, particularly hydrilla.

LAYOUT OF SITE FOR COLLECTION OF DATA

To facilitate the collection of data, the WES has established a system of 14 control transects for the test site (Figure 6). These were selected after consideration of the general characteristics of the area as revealed by aerial photographs and on-site inspection. Eleven permanent stations have been established at selected points along these transects. These are designated as control stations and will provide reference points for locating sampling points to be used throughout the period of the LSOMT. In addition, supplementary data stations may be established by the individual contractors for collecting additional data that they think may be necessary. (These permanent control data stations will enable us to possibly determine causes due to subtle changes in the system because of the amount of different data being collected in close proximity.)

All sampling points used at every sampling interval will be referenced on a gridded blank map provided by the WES, to be submitted with the data to the WES (Figure 7).

STOCKING OF WHITE AMUR

In addition to considering the lake system as a total water body, each of the five pools that comprise

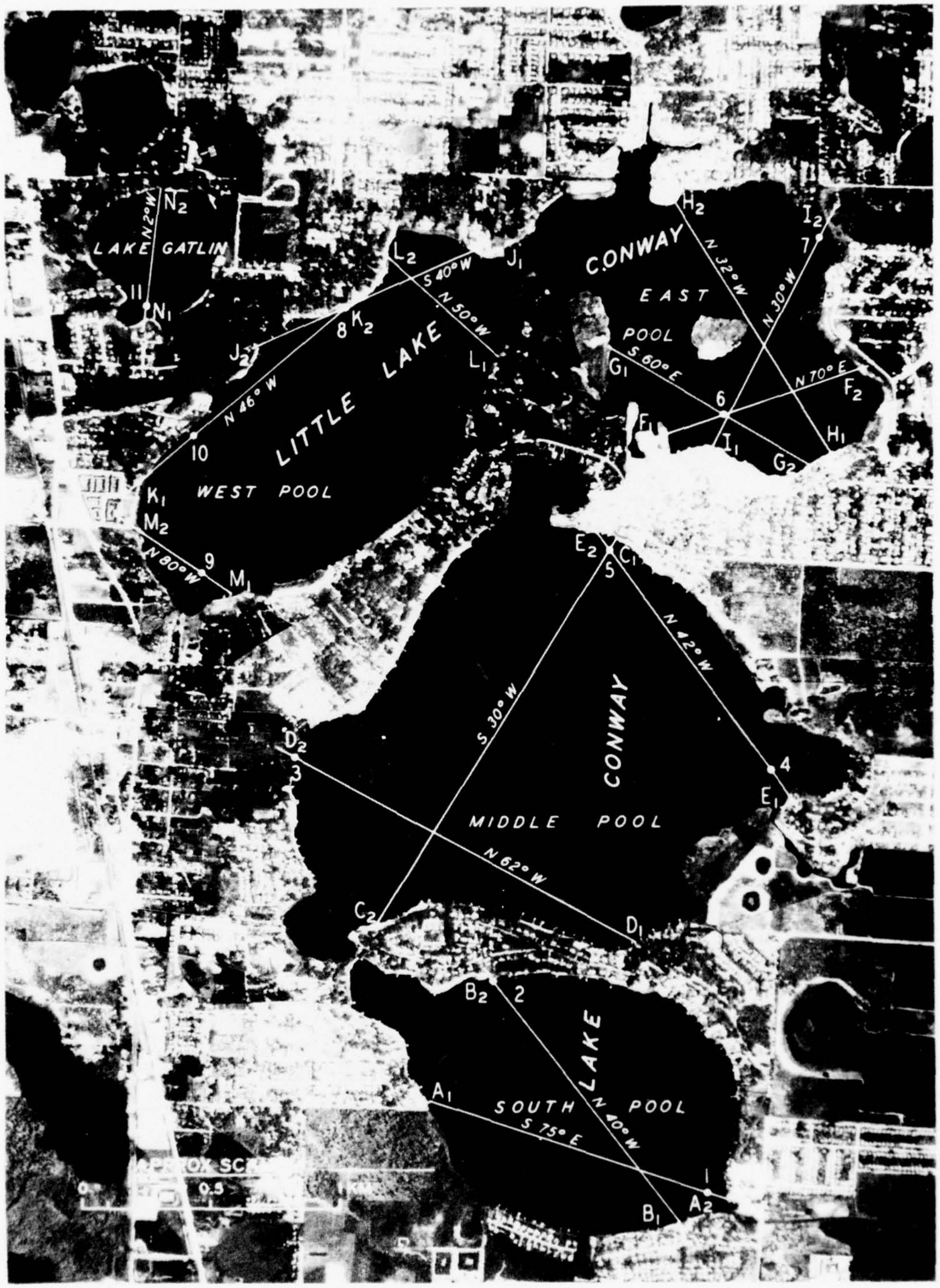

Figure 6. Control transects and data stations for Lake Conway, Florida, complex

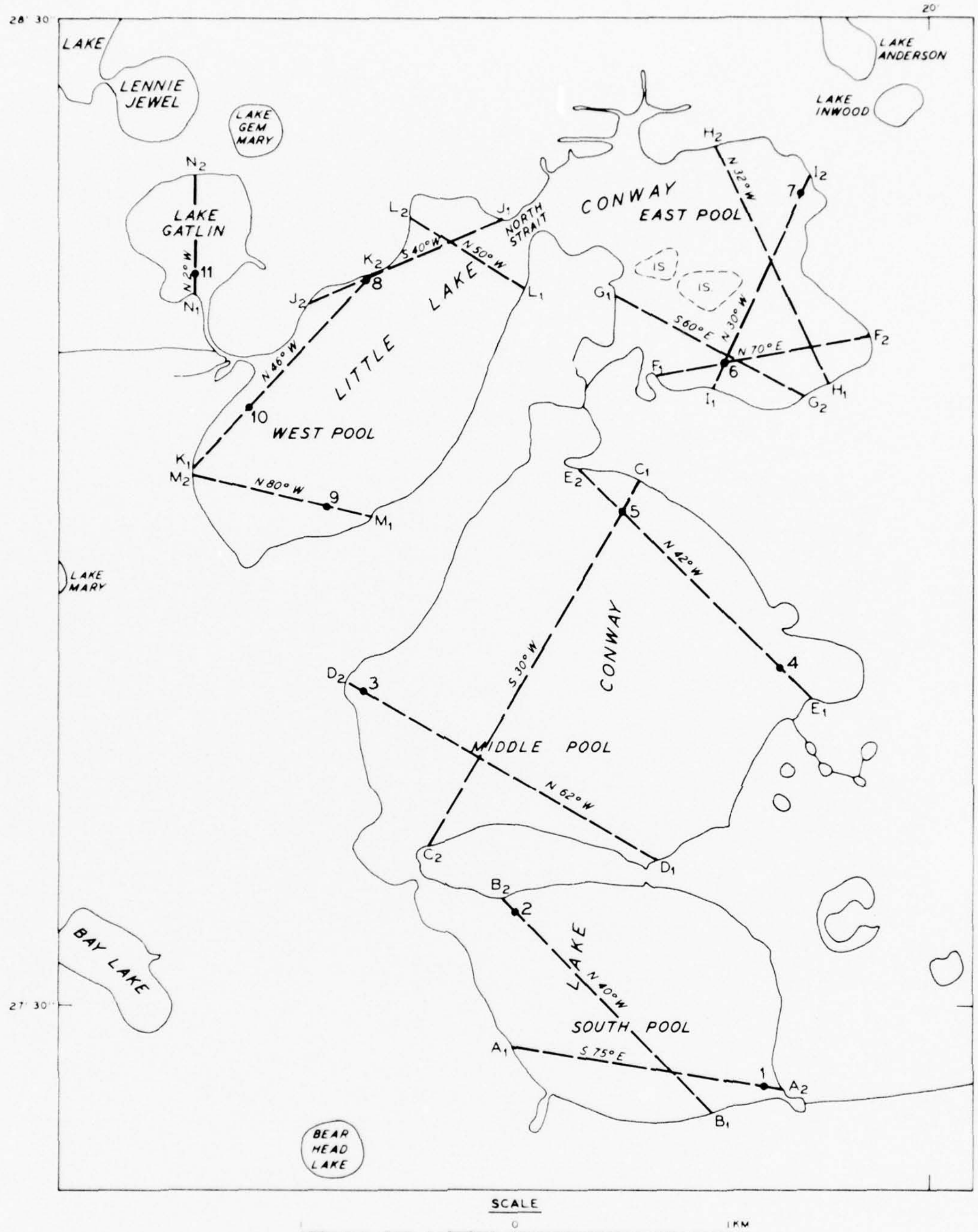

Figure 7. Blank map for indicating sampling locations in Lake Conway, Florida, complex

the Lake Conway system will be considered separately for stocking purposes. The total submersed vegetation (standing crop) existing in each pool, as well as the time selected for achieving control, will determine the individual stocking rates regardless of surface acres of water involved. The standing crop of all plant species will be determined from data collected monthly by the Florida Department of Natural Resources. These data in association with the results obtained from a stocking model will be used to determine the total number of fish needed to stock each of the pools in the test site.

The stocking rate will, in part, be determined by the size of the fish at the time of release. We are obtaining monthly reports from the Fish Farming Experimental Station in Stuttgart on the growth of the monosex fish population. From these reports we will be able to predict what the size of the fish will be upon release.

One of our major logistical problems is getting the fish population from Stuttgart, Arkansas, to Orlando, Florida. Transporting of the fish will be done by a commercial fish farmer from the Stuttgart area. He will be under contract to haul the white amur from the rearing ponds in Stuttgart to the test site at Lake Conway. The vehicle used to transport the fish to Florida will be a compartmented tank truck with a carrying capacity of 15,000 lb of fish. The truck will be loaded in Stuttgart in the afternoon and travel overnight, arriving at a WES-designated release site on Lake Conway the next day (travel time approximately 20 hr). Upon arrival at the release site, load mortality will be estimated. In addition, representative samples of the fish will be taken (in accordance with arrangements made with the FG&FWFC) to the Florida State Fish Hatchery at Rich Loam to be subsequently observed for determination of long-range mortality.

Several access sites for stocking each pool have undergone preliminary evaluation and two sites in each pool have been chosen, based on accessibility and loading capacity (Figure 8). Just prior to release, an additional evaluation of release sites will be made. In cases where we feel the release sites will not accommodate the size of the large tank truck, we will transfer fish to a smaller fish truck for release.

In the test plan, it was mentioned that we were considering marking the fish prior to introduction. After considering all aspects, we decided not to mark the fish. This decision was based on a number of reasons, i.e., considering the small number of fish at our disposal, we could not afford to lose very many in handling while marking. Also, the time of the year is critical. Because of cold weather, the fish would not heal rapidly from the marking technique and it would be very difficult to determine mortality once they were released. As I mentioned earlier, baseline data are being collected. We plan to introduce the fish the latter part of February 1977.

LONG-RANGE PLANS

After introduction of the white amur into Lake Conway, it is planned that the contractors will continue to intensely monitor the system for 2 to 3 years. After this time, the WES will continue to monitor the system much less frequently for as long as it is advantageous to do so.

It should be emphasized that by control we do not mean complete eradication of the aquatic vegetation. Plant control is a goal that can only be reached within relatively broad limits because of the growth dynamics of both the control agent and the weed population. It is anticipated that control can be effected at Lake Conway in 3 to 5 years without danger of removing so much vegetation that the ecosystem will become unbalanced.

Figure 8. Locations of fish release sites

BASELINE DATA REPORT—LAKE CONWAY GRASS CARP PROJECT

by

V. Guillory,* R. Land,* and R. Gasaway**

INTRODUCTION

The U. S. Army Engineer Waterways Experiment Station is sponsoring a large-scale, multiorganizational field test to determine the efficacy and environmental effects of grass carp in conjunction with herbicides to control *hydrilla* in the Lake Conway Chain. As data on the environmental effects and weed control of grass carp in large lake systems are lacking, research findings will provide a working base for the future use and management of grass carp in Florida's public waters.

The Fisheries Division of the Florida Game and Fresh Water Fish Commission was contracted to monitor the fish, waterfowl, and aquatic mammal populations and sport fishery in the Lake Conway system before and after introduction of monosex grass carp in February 1977. In order to evaluate the potential effects of grass carp introduction upon Lake Conway, baseline conditions as they exist before grass carp introduction are being described for comparison with data after grass carp introduction.

Evaluation of changes associated with the introduction of grass carp will be determined using the following techniques:

a. Life history information is derived from four fish of divergent trophic levels and ecological habits—chain pickerel, bluefin killifish, bluegill, and largemouth bass.

b. Six sampling methods, wegener ring, electrofishing, gill net, blocknet-rotenone, 10-ft seine, and 20-ft seine, are used to determine the distribution, species composition, diversity, and abundance of fishes according to habitat types.

c. Sport fishing is measured by a stratified random creel survey utilizing nonuniform probability sampling.

d. Waterfowl and aquatic mammals are sampled by direct count.

The purpose of this report is to present methods utilized and certain aspects of the Lake Conway sport fishery and fish population data collected thus far.

MATERIALS AND METHODS

Fish Sampling

Six sampling methods were used on Lake Conway to determine the distribution, species composition, diversity, and abundance of fishes: blocknet samples in June, 20-ft seine and wegener ring from May through September, and 10-ft seine, gill net, and electrofishing from July to September.

Two wegener ring samples were taken at each of six stations monthly in shallow, heavily vegetated, littoral areas. Five blocknets were taken in deeper littoral habitats. Both methods are quantative and were used to determine the approximate standing crop, abundance, and species composition of fishes in sampled habitats.

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Two seine collections accompanied wegener ring samples monthly at each sample station. One seine collection of five hauls was taken in unvegetated "beach" habitats with a 20-ft seine, and the other adjacent to emergent vegetation with a 10-ft seine. One hour of electrofishing at six stations was undertaken monthly in littoral areas, with each station subdivided into naturally vegetated and beach habitats and electrofished for 30 min each. Sinking and floating gill nets 150 ft long were set overnight monthly at each of four stations in limnetic areas. Seine, gill net, and electrofishing samples were used to describe the species composition and relative abundance of fishes occupying the respective habitats sampled.

Creel Census

Sport fishing was measured by a stratified random roving creel survey utilizing nonuniform probability sampling as generally described by Pfeiffer[1] and more specifically for Florida by Ware, Fish, and Prevatt[2]. Stratification of this survey involves random selection with nonuniform probabilities of periods of time and days (weekday and weekend). Five days, including at least one weekend day, were selected for creel surveying in each 2-week period. Each day was divided into four periods (0700-1000, 1000-1300, 1300-1600, 1600-1900) with probabilities assigned in proportion to daily variations in fishing pressure.

As employed on Lake Conway, interviewed anglers were requested to provide the following information: time spent fishing (effort), number and kind of fish caught (yield), and species sought. During each creel period a count was made of the number of anglers present at a given time. This count is termed an "instantaneous count" and is used in conjunction with other interview data to derive expanded (total) estimates of yield, effort, and catch per unit effort.

Creel census data are normally coded and submitted to the Southeastern Cooperative Fish and Game Statistics Project located in North Carolina State for computer-derived estimates of total and species yield, harvest, and catch per unit effort. However, as these data are submitted quarterly, hand-computed success rates for species fished for are presented in this report:

Waterfowl and Aquatic Mammal Sampling

Waterfowl and aquatic mammals are sampled monthly by direct counts from boats. Number and species are recorded. Sampling will be sufficient to detect gross but not detailed changes over the study period.

Fish Life History

Life history information is derived from selected species to monitor possible changes following the introduction of grass carp. Four species of divergent trophic levels and ecological habits are emphasized: chain pickerel (*Esox niger*), bluefin killifish (*Lucania goodei*), bluegill (*Lepomis macrochirus*), and largemouth bass (*Micropterus salmoides*). Other species are being examined in conjunction with other statewide fishery research projects.

Representatives of the four major species are being examined monthly for sex and gonadal development. Ova counts are made on gravid females for fecundity analysis. Game fish reproduction success is measured in terms of numbers of juveniles which appear in seine, wegener ring, and blocknet samples.

The overall population structure of the population and growth, if possible, of selected species will be determined from length frequency data. Condition factors, a means of evaluating fish condition by

mathematically defining robustness, will be determined on the selected game species according to the formula $K = (W/L^3) \times 10^5$ (Lagler[3]). The length-weight relationship of selected sport species will be derived from the regression line of length and weight, where $\log W = \log c + b (\log L)$ (Lagler[3]).

Ten specimens of each species will be taken monthly for food habit analysis. Stomach contents are identified and enumerated.

Changes in condition, length-weight relationships, and food habits will be used to evaluate food chain changes associated with grass carp introduction.

Field Data Analysis

Species diversity. Number of species is the simplest way to describe the diversity of an assemblage and, as illustrated by Poole,[4] the only truly objective measure of species diversity. However, more meaningful analysis of natural communities involves mathematical diversity indices. The biotic diversity is dependent upon the number of species present (species variety or richness) and the numerical distribution of species among the assemblage (equitability). In low-diversity communities, a few species tend to be numerically dominant and number of species is relatively low, i.e., equitability and richness are reduced. In areas of high diversity, a larger number of species and more even numerical distribution among the species are characteristic. It is important to consider both species richness and equitability separately, as number of species depends primarily on the structural diversity of a habitat, whereas equitability is more sensitive to the stability of physical conditions (Lloyd and Ghelardi[5]).

Information theory is one method of species diversity analysis. In this case, diversity is related to the degree of uncertainty of any randomly selected individual. One information theory formula, which is sensitive to both numbers of species and the relative distribution of individuals among the species, is based on the machine formula presented by Lloyd, Zar, and Karr:[6]

$$S = \frac{c}{h}$$

where

S = success or catch of species "a" per hour of fishing for a given species

c = catch of that species by fishermen fishing for the species

h = hours of fishing for this species

Mean diversity, as calculated above, may range from zero to 3.3219 log N.

Because the value of $\bar{d}$ is determined by both species richness and equitability, statistical procedures have been developed for separate calculations of these two components of diversity. The species richness was determined by the following (Margalef[7]):

$$\bar{d} = \frac{C}{N}\left(N \log 10N - n_i \log 10n_i\right)$$

where

C = 3.321928 (converts base 10 log to base 2)

N = total number of individuals

n_i = number of individuals in species i

To evaluate the diversity component due to the distribution of individuals among the species, the calculated $\bar{d}$ value is compared with hypothetical maximum $\bar{d}$ based on an arbitrarily selected distribution where all species are equally abundant—McArthur's[8] "broken stick" model. Lloyd and Ghelardi[5] devised a table for determining equitability by comparing the number of species (S) in the sample with the number of species expected (S') from a community that conforms to McArthur's model.

$$D = \frac{S}{\log N}$$

where

S = number of species

N = number of individuals

Equitability, as calculated, may range from 0 to 1 except in the unusual situation where the distribution in the samples is more equitable than the distribution resulting from the McArthur model, which occasionally occurs in samples containing only a few specimens with several taxa represented.

It should be noted these methods are theoretically based and when used together provide insight into species diversity. Each may be questionable alone.

Dominance ranking. Ono's[9] method of assessing the relative abundance and frequency of occurrence of species was utilized with certain modification to meet present needs. For each taxon the number of occurrences in all gear types is plotted against its ranking score as determined by Sanders' biological index (Sanders[10]). This biological index is used to measure relative abundance by assigning rankings in pooled samples for each gear type for the 15 most common species so that 15 points are given to the most abundant species, 14 points to the second most abundant species, and so forth. Scores for each species in all methods are then summed and species are ranked accordingly.

These values are placed on a graph that is divided into quadrants by solid lines representing mean values of occurrence and Sanders' biological index for all species. Dominant species (i.e. those that occur frequently and in large numbers) appear in the upper-right quadrant, whereas species in the upper-left quadrant have a low frequency but when present are very abundant. Species in the lower-left quadrant are uncommon in both abundance and frequency, with species in the lower-right quadrant occurring frequently but seldom in large numbers.

RESULTS

Abundance

Blocknet. Blocknet samples in Lake Conway produced an average of 19,629 fish/ha, weighing 133.15 kg (Table 1). Numerically, the most abundant species was the bluespotted sunfish, which yielded 12,697/ha and comprised 64.42 percent of the total catch. Largemouth bass were second in abundance with 1,398/ha (7.10 percent), followed by bluefin killifish with 1,811 (9.19 percent), warmouth with 1,081 (5.49 percent), redear sunfish with 985 (5.00 percent), and bluegill with 965 (4.90 percent). An additional 14 species were encountered in blocknet samples, but all comprised less than 1.0 percent of the total catch.

By weight, the dominant species was redear sunfish with 31.88 kg/ha (23.94 percent), followed by bluegill and largemouth bass with 25.09 (18.84 percent), and 23.77 (17.85 percent) kg/ha, respectively. Chain pickerel with 19.89 (14.93 percent) and bluespotted sunfish with 16.34 (12.27 percent) kg/ha were

Table 1

Average Blocknet Yield Per Hectare and Percent Composition of Fishes in Lake Conway—June 1976 (N = 5)

Species	c/f* No.	c/f* Weight kg	Percent Composition No.	Percent Composition Weight
Florida gar	0.20	0.30	0.01	0.23
Gizzard shad	0.40	0.37	0.01	0.28
Threadfin shad	28.40	0.53	0.14	0.40
Chain pickerel	130.20	19.89	0.66	14.93
Golden shiner	2.40	0.21	0.01	0.16
Coastal shiner	8.16	0.10	0.41	0.08
Brown bullhead	142.00	4.59	0.72	3.44
Tadpole madtom	1.00	0.01	0.01	0.01
Seminole killifish	54.40	0.08	0.28	0.06
Bluefin killifish	1,810.60	2.19	9.19	1.64
Least killifish	10.00	0.01	0.05	0.01
Brook silverside	11.40	0.04	0.06	0.03
Bluespotted sunfish	12,696.60	16.34	64.42	12.27
Warmouth	1,081.20	5.65	5.49	4.26
Bluegill	965.20	25.09	4.90	18.84
Dollar sunfish	102.40	0.76	0.52	0.57
Redear sunfish	985.20	31.88	5.00	23.94
Largemouth bass	1,398.40	23.77	7.10	17.85
Black crappie	195.00	1.25	0.99	0.93
Swamp darter	6.20	0.09	0.03	0.06
Total	19,629.36	133.15	100.00	100.00

* Number of organisms per unit effort.

the only other species comprising more than 5.0 percent of the total weight.

Sport fishes as a group averaged 4,755 individuals/ha weighing 117.03 kg in Lake Conway blocknet samples (Table 2). Forage fishes yielded 14,805 individuals and 20.71 kg/ha. Thus, sport fishes dominated by weight (82.05 percent of the total), whereas forage fishes were numerically dominant (75.14 percent of the total). The "other" category was relatively insignificant in numbers and biomass.

Harvestable sport fish in blocknet samples averaged 220/ha weighing 61.65 kg (Table 3). Redear sunfish ranked number one in number (98/ha) and biomass (18.63 kg/ha). Largemouth bass, the most sought after sport fish, yielded 28 harvestable fish/ha weighing 18.19 lb. Chain pickerel (much potential but unused by fisheries) averaged 36 harvestable fish weighing 17.41 kg/ha.

Wegener ring. Wegener ring shallow-water samples, on the average, yielded a total of 27.18 fish weighing 23.56 g per collection (coll) (Table 4). Numerically, two species comprised 70 percent of the total number—mosquitofish with 13.20/coll and bluefin killifish with 5.83/coll. An additional three species, including Seminole killifish, swamp darter, and coastal shiner yielded between 1.0 and 2.5/coll. Bluefin killifish contributed the most biomass—7.68 g/coll. Bluegill, mosquitofish, Seminole killifish, and warmouth produced an average of 2 to 3.5 g/coll.

Table 2

Average Number and Kilograms of Sport, Forage, and Other Fish Per Hectare in Lake Conway Blocknet Samples—June 1976 (N = 5)

Category	c/f* No.	c/f* Weight kg	Percent Composition No.	Percent Composition Weight
Sport fish	4,755.2	117.03	24.13	82.05
Chain pickerel				
Warmouth				
Bluegill				
Redear sunfish				
Largemouth bass				
Black crappie				
Forage fish	14,805.4	20.71	75.14	14.52
Gizzard shad				
Threadfin shad				
Golden shiner				
Coastal shiner				
Tadpole madtom				
Seminole killifish				
Bluefin killifish				
Least killifish				
Brook silverside				
Bluespotted sunfish				
Dollar sunfish				
Swamp darter				
Other fish	142.9	4.89	0.73	3.43
Florida gar				
Brown bullhead				
Total	19,703.5	142.63	100.00	100.00

* Number of organisms per unit effort.

Table 3

Average Number and Weight Per Hectare of Harvestable Sport Fish from Blocknet Samples in Lake Conway—May 1976 (N = 5)

Species	No.	Weight, kg
Chain pickerel, ≥12 in.	36	17.41
Warmouth, ≥5 in.	3	0.54
Bluegill, ≥6 in.	52	6.43
Redear sunfish, ≥6 in.	98	18.63
Largemouth bass, ≥10 in.	28	18.19
Black crappie, ≥9 in.	3	0.45
Total	220	61.65

Table 4

Average Wegener Ring Yield Per Collection and Percent Composition of Fishes in Lake Conway—May Through September 1976 (N = 60)

Species	c/f*		Percent Composition	
	No.	Weight, g	No.	Weight
Florida gar	0.03	0.06	0.11	0.24
Coastal shiner	1.10	0.67	4.06	2.85
Brown bullhead	0.10	0.06	0.36	0.26
Golden topminnow	0.56	0.63	2.06	2.68
Seminole killifish	2.32	2.91	8.54	12.32
Flagfish	0.02	0.01	0.07	0.01
Bluefin killifish	5.83	7.68	21.44	32.61
Least killifish	0.07	0.01	0.24	0.04
Mosquitofish	13.20	3.03	48.58	12.86
Brook silverside	0.02	0.01	0.07	0.05
Bluespotted sunfish	0.46	0.55	1.70	2.32
Warmouth	0.53	2.51	1.95	10.67
Bluegill	0.54	3.14	2.00	13.38
Redear sunfish	0.30	0.71	1.10	3.02
Spotted sunfish	0.02	0.01	0.07	0.01
Largemouth bass	0.43	0.80	1.57	3.41
Swamp darter	1.65	0.77	6.08	3.27
Total	27.18	23.56	100.00	100.00

* Number of organisms per unit effort.

20-ft seine. An average of 69 fish weighing 413.3 g were taken in each 20-ft seine collection (Table 5). Seminole killifish dominated the samples, yielding 58 individuals (84.11 percent) and 265.8 g (64.31 percent)/coll. Four species, in order of abundance, were taken from 1 to 4 times/coll: bluegill, coastal shiner, redear sunfish, and largemouth bass. Biomass-wise, redear sunfish (71.8 g/coll), bluegill (60.3 g/coll.), and largemouth bass (12.8/coll) followed Seminole killifish.

10-ft seine. Ten-foot seine samples yielded an average of 22.6 fish weighing 73.07 g (Table 6). Four species numerically dominated these samples: bluegill with 6.16/coll (27.30 percent), coastal shiner with 6.00/coll (26.58 percent), bluefin killifish with 3.61/coll (16.00 percent), and mosquitofish with 2.66/coll (11.79 percent). Seminole killifish and largemouth bass were collected at a rate of 1.16 and 0.94/coll, respectively, Florida gar, with an average yield of 32.83 g/coll (44.98 percent) contributed the greatest biomass, followed by bluegill with 12.88 g/coll (17.64 percent) and Seminole killifish with 6.11 g/coll (8.36 percent).

Electrofishing. In electrofishing samples taken in "beach" areas, an average of 733 individuals weighing 22,996.3 g were collected per hour (Table 7). In comparison, sampling in heavily vegetated habitats yielded approximately 291 fish/hr weighing 17,342.7 g (Table 8). Thus according to electrofishing samples, beach zones harbored a greater density of fishes, and these fishes were larger than those found in vegetated areas.

Table 5

Average Yield Per 20-ft Seine Collection* and Percent Composition of Fishes in Lake Conway—May Through September 1976 (N = 30)

Species	c/f** No.	c/f** Weight, g	Percent Composition No.	Percent Composition Weight
Coastal shiner	3.0	1.9	4.34	0.46
Golden topminnow	0.1	0.2	0.14	0.05
Seminole killifish	58.2	265.8	84.11	64.31
Bluefin killifish	0.2	0.1	0.29	0.02
Mosquitofish	0.3	0.1	0.43	0.02
Brook silverside	0.3	0.3	4.43	0.07
Bluegill	3.2	60.3	4.62	14.59
Redear sunfish	2.6	71.8	3.76	17.37
Largemouth bass	1.3	12.8	1.88	3.11
Total	69.2	413.3	100.00	100.00

* Each collection entails five seine hauls.
** Number of organisms per unit effort.

Table 6

Average Yield Per 10-ft Seine Collection* and Percent Composition of Fishes in Lake Conway—July Through September 1976 (N = 18)

Species	c/f** No.	c/f** Weight, g	Percent Composition No.	Percent Composition Weight
Florida gar	0.05	32.83	0.22	44.98
Chain pickerel	0.11	3.44	0.49	4.71
Coastal shiner	6.00	3.66	26.58	5.01
White catfish	0.05	0.01	0.24	0.01
Golden topminnow	0.05	0.16	0.24	0.22
Seminole killifish	1.16	6.11	5.13	8.36
Bluefin killifish	3.61	1.33	16.00	1.82
Mosquitofish	2.66	0.75	11.79	1.03
Bluespotted sunfish	0.66	0.58	2.94	0.79
Warmouth	0.05	0.17	0.24	0.23
Bluegill	6.16	12.88	27.30	17.64
Redear sunfish	0.61	0.25	2.70	0.34
Largemouth bass	0.94	5.27	4.17	7.22
Black crappie	0.44	5.58	1.96	7.64
Total	22.55	73.02	100.00	100.00

* Each collection entails five seine hauls.
** Number of organisms per unit effort.

Table 7

Electrofishing Harvest Per Hour and Percent Composition of Fishes in "Beach" Zones in Lake Conway—July Through September 1976 (N = 18)

Species	c/f* No.	c/f* Weight, g	Percent Composition No.	Percent Composition Weight
Longnose gar	0.2	6.2	0.03	0.03
Florida gar	0.7	382.5	0.09	1.66
Gizzard shad	0.7	538.4	0.09	2.34
Threadfin shad	83.3	513.5	11.36	2.23
Chain pickerel	4.0	1,489.6	0.54	6.48
Golden shiner	6.4	217.4	0.87	0.94
Coastal shiner	7.6	9.3	1.04	0.04
Lake chubsucker	1.3	507.1	0.18	2.20
Seminole killifish	33.1	204.8	4.51	0.89
Brook silverside	61.8	57.4	8.43	0.25
Bluespotted sunfish	0.2	0.1	0.03	0.01
Warmouth	0.4	0.3	0.05	0.01
Bluegill	355.3	9,809.7	48.45	42.64
Dollar sunfish	0.2	0.8	0.03	0.01
Redear sunfish	117.1	4,568.4	15.97	19.87
Spotted sunfish	0.2	12.7	0.03	0.06
Largemouth bass	59.8	4,597.8	8.15	19.98
Black crappie	0.9	80.1	0.12	0.35
Swamp darter	0.2	0.2	0.03	0.01
Total	733.4	22,996.3	100.00	100.00

* Number of organisms per unit effort.

Numerically, bluegill with 143.3 fish/hr (49.27 percent) dominated in vegetated areas, followed by redear sunfish with 39.1/hr (13.45 percent), warmouth with 30/hr (10.31 percent) and largemouth bass with 28.2/hr (9.69 percent). Similarly, in beach zones bluegill was the most abundant species with 355.3/hr (48.45 percent) and redear sunfish with 117.1/hr (15.97 percent), the second most abundant species. Threadfin shad and brook silverside ranked third and fourth in numerical abundance in beach areas with 83.3/hr (11.33 percent) and 61.8/hr (8.43 percent), respectively.

In both vegetated and beach collections, bluegill contributed the greatest amount of biomass with 4257 g/hr (24.55 percent) and 9809 g/hr (42.62 percent), respectively. Chain pickerel, redear sunfish, bowfin, Florida gar, and largemouth bass all averaged between 1100 and 3100 g/hr in vegetated areas. Six species (largemouth bass, redear sunfish, chain pickerel, gizzard shad, threadfin shad, lake chubsucker) yielded between 500 and 4600 g/hr in beach zones.

Gill net. An average of 33 fish and 20.07 kg per net day were taken in gill nets (Table 9). Gizzard shad and Florida gar dominated both numerically and weight-wise—gizzard shad with 12.9 individuals (38.85 percent) and 8.38 kg (41.75 percent)/net day, Florida gar with 8.2 individuals (24.70 percent) and 7.26 kg (36.17 percent)/net day. Black crappie, largemouth bass, and bluegill all yielded between 1.5 and

Table 8

Electrofishing Harvest Per Hour and Percent Composition of Fishes in Vegetated Areas in Lake Conway—July Through September 1976 (N = 18)

Species	c/f* No.	c/f* Weight, g	Percent Composition No.	Percent Composition Weight
Florida gar	2.7	1,234.2	0.92	7.12
Bowfin	0.9	2,504.0	0.30	14.43
Gizzard shad	0.2	144.3	0.07	0.84
Threadfin shad	14.4	155.3	4.95	0.90
Chain pickerel	13.1	3,073.6	4.50	17.72
Golden shiner	4.0	358.6	1.38	2.07
Coastal shiner	0.2	0.2	0.07	0.01
Lake chubsucker	1.6	786.9	0.55	4.53
Yellow bullhead	0.7	124.6	0.23	0.72
Brown bullhead	0.9	222.3	0.30	1.28
Seminole killifish	1.3	6.8	0.46	0.04
Mosquitofish	0.4	0.1	0.14	0.01
Brook silverside	4.4	3.8	1.51	0.02
Bluespotted sunfish	0.7	0.8	0.24	0.01
Warmouth	30.0	196.3	10.31	1.13
Bluegill	143.3	4,257.8	49.27	24.55
Dollar sunfish	0.4	1.7	0.14	0.01
Redear sunfish	39.1	2,574.1	13.45	14.83
Spotted sunfish	2.4	52.1	0.83	0.30
Largemouth bass	28.2	1,125.6	9.69	6.48
Black crappie	2.0	519.6	0.69	3.00
Total	290.9	17,342.7	100.00	100.00

* Number of organisms per unit effort.

4.0 specimens/net day, or greater than 4 percent of the total. Largemouth bass, black crappie, and chain pickerel each comprised from 3.0 to 11.0 percent of the total weight and yielded more than 0.50 kg/net day.

Species Diversity

Number of species. Overall, a total of 31 species were collected in Lake Conway from May through September 1976 (Table 10). A greater number of species were collected by electrofishing than any other method—23. Electrofishing in beach areas yielded a total of 19 species, whereas 21 were collected in vegetated habitats. Twenty species were taken in blocknet samples, 14 with the 10-ft seine, 12 by gill nets, and 9 by 20-ft seine.

Table 11 illustrates the monthly variation in number of species collected per gear type. The range and mean number (in parentheses) of species in each gear method was as follows: wegener ring, 10-14 (11.8); 20-ft seine, 6-8 (6.4); 10-ft seine, 10-11 (10.7); gill net, 8-10 (9.7); electrofishing-vegetation, 16-21

Table 9

Average Yield Per Gill Net Day* and Percent Composition of Fishes in Lake Conway—July Through September 1976 (N = 12)

Species	c/f**		Percent Composition	
	No.	Weight, kg	No.	Weight
Florida gar	8.2	7.26	24.70	36.17
Gizzard shad	12.9	8.38	38.85	41.75
Chain pickerel	0.8	0.65	2.41	3.23
Golden shiner	0.9	0.14	2.71	0.70
Lake chubsucker	0.3	0.28	0.90	1.40
White catfish	0.1	0.07	0.30	0.35
Yellow bullhead	0.4	0.12	1.20	0.60
Brown bullhead	0.1	0.04	0.30	0.20
Bluegill	1.5	0.14	4.53	0.70
Redear sunfish	0.3	0.06	0.90	0.30
Largemouth bass	3.8	2.07	11.45	10.31
Black crappie	3.9	0.86	11.75	4.29
Total	33.2	20.07	100.00	100.00

* One net day equals 150 ft of net fished for 24 hr.
** Number of organisms per unit effort.

(18.3); electrofishing-beach 13-14 (13.3). The number of species collected in five blocknet samples taken in June ranged from 12 to 14, with a mean of 13 (Table 12).

Information theory. According to information theory, electrofishing in vegetation reflected the highest species diversity with a monthly range from 2.35 to 2.67 and a mean of 2.50 (Table 11). Ten-ft seine samples ranked second, with a mean species diversity of 2.38 and a range of 1.93 to 2.84. Mean values for the remaining gear types were: gill net, 2.26; wegener ring, 2.23; electrofishing-beach, 2.01; blocknet, 1.84; and 20-ft seine, 1.03.

Species richness. Electrofishing in vegetation produced the highest species richness index—a range from 6.11 to 7.73 and a mean of 6.86 (Table 11). Data derived from 10-ft seine samples resulted in the second highest index with a mean of 5.20 and a range of 5.14 to 5.32. In order of rank, the other sampling methods produced the following mean index values: wegener ring, 4.81; electrofishing-beach, 4.37; blocknet, 3.40; and 20-ft seine, 2.56.

Species equitability. Gill net and 10-ft seine samples reflected the highest equitability indices—a mean of 0.76 (0.66 to 0.93) with gill nets and mean of 0.75 (0.45 to 0.91) according to the 10-ft seine (Table 11). The remaining methods were fairly close in mean values of this index: wegener ring, 0.53 (0.50 to 0.57); electrofishing-beach, 0.41 (0.31 to 0.57); 20-ft seine, 0.40 (0.24 to 0.58); and blocknet, 0.36 (0.29 to 0.40).

Dominance Rank

The dominance rank, according to abundance and frequency of occurrence encompassing all gear types, of all species collected is depicted in Figure 1. Eleven species appear in the upper-right quadrant,

Table 10
Checklist of Fishes from Lake Conway

Family	Common Name	Scientific Name
Lepisosteidae	Longnose gar	*Lepisosteus osseus*
	Florida gar	*Lepisosteus platyrhynchus*
Amiidae	Bowfin	*Amia calva*
Clupeidae	Gizzard shad	*Dorosoma cepedianum*
	Threadfin shad	*Dorosoma petenense*
Esocidae	Redfin pickerel	*Esox americanus*
	Chain pickerel	*Esox niger*
Cyprinidae	Golden shiner	*Notemigonus crysoleucas*
	Coastal shiner	*Notropis petersoni*
Catostomidae	Lake chubsucker	*Erimyzon sucetta*
Ictaluridae	White catfish	*Ictalurus catus*
	Yellow bullhead	*Ictalurus natalis*
	Brown bullhead	*Ictalurus nebulosus*
	Tadpole madtom	*Noturus gyrinus*
Aphredoderidae	Pirate perch	*Aphredoderus sayannus*
Cyprinodontiae	Golden topminnow	*Fundulus chrystotus*
	Seminole killifish	*Fundulus seminolis*
	Flagfish	*Jordanella floridae*
	Bluefin killifish	*Lucania goodei*
Poeciliidae	Mosquitofish	*Gambusia affinis*
	Least killifish	*Heterandria formosa*
Atherinidae	Brook silverside	*Labidesthes sicculus*
Centrachidae	Bluespotted sunfish	*Ennecanthus glorisus*
	Warmouth	*Lepomis gulosus*
	Bluegill	*Lepomis macrochirus*
	Dollar sunfish	*Lepomis marginatus*
	Redear sunfish	*Lepomis microlophus*
	Spotted sunfish	*Lepomis punctatus*
	Largemouth bass	*Micropterus salmoides*
	Black crappie	*Pomoxis nigromaculatus*
Percidae	Swamp darter	*Etheostoma fusiforme*

which includes only those species occurring in above-average numbers and frequency of occurrences. Bluegill had the highest biological index value (53), hence, the greatest abundance; whereas, largemouth bass appeared most frequently in all samples (93). Bluegill and largemouth bass also ranked second in frequency (82) and abundance (42), respectively. Clustered in the lower-left corner of this quadrant, hence with slightly above-average abundance and occurrences, are four species, including threadfin shad, chain pickerel, brook silverside, and black crappie. Scattered throughout the middle portion of the upper-left quadrant are four additional species, presented with their order of abundance and occurrence, respectively: Seminole killifish, fourth and third; redear sunfish, third and fourth;

Table 11

Variation in Number of Species and Species Diversity Indices (Information Theory—Machine Method, Species Richness, and Species Equitability) for Monthly Pooled Samples for Each Gear Type

	May	June	July	August	September
Wegener ring					
No. of species	10	10	13	12	14
Information theory	2.01	1.96	2.43	2.29	2.37
Species richness	4.09	4.18	5.40	5.44	4.93
Species equitability	0.53	0.51	0.57	0.54	0.50
20-ft seine					
No. of species	7	5	6	6	8
Information theory	0.57	0.61	1.05	1.48	1.46
Species richness	2.34	1.93	2.39	2.73	3.43
Species equitability	0.24	0.35	0.42	0.58	0.43
10-ft seine					
No. of species			11	10	11
Information theory			2.84	2.69	1.93
Species richness			5.32	5.14	5.16
Species equitability			0.91	0.89	0.45
Gill net					
No. of species			10	8	8
Information theory			2.30	2.06	2.43
Species richness			4.48	3.79	3.95
Species equitability			0.66	0.69	0.93
Electrofishing—beach					
No. of species			14	13	13
Information theory			1.77	1.83	2.45
Species richness			4.68	4.20	4.24
Species equitability			0.31	0.36	0.57
Electrofishing—vegetation					
No. of species			21	18	16
Information theory			2.67	2.35	2.48
Species richness			7.73	6.76	6.11
Species equitability			0.43	0.38	0.58

Table 12

Variation in Number of Species and Species Diversity Indices (Information Theory—Machine Method, Species Richness, Species Equitability) in Blocknet Samples in Lake Conway, June 1976

	Samples				
	1	2	3	4	5
No. of species	13	12	14	12	14
Information theory	1.56	1.87	1.94	1.79	2.07
Species richness	3.57	2.87	3.77	3.27	3.52
Species equitability	0.29	0.40	0.36	0.36	0.40

mosquitofish, seventh and fifth; bluefin killifish, fourth and sixth; and coastal shiner, sixth and seventh.

Species found in the upper-left quadrant have an above-average abundance but a below-average frequency of occurrence. Bluespotted sunfish and warmouth are located in this quadrant.

Sixteen species are enclosed by the lower-right quadrant. These species have below-average abundances and frequency of occurrences. Six species have a biological index value of 1 or less and a frequency of occurrence of less than 8: longnose gar, tadpole madtom, flagfish, white catfish, bowfin, least killifish, dollar sunfish, and spotted sunfish. Three species (Florida gar, gizzard shad, golden shiner) found in the upper-right corner of this quadrant reflect abundance and occurrence data only slightly below average. Five additional species are found roughly in the middle portion of the quadrant: lake chubsucker, yellow bullhead, brown bullhead, golden topminnow, and swamp darter.

Sport Fishery

At this time, only relative effort, relative harvest, and species directed catch per man-hour are available on the sport fishery on Lake Conway (Table 13). The largemouth bass fishery dominated, comprising 94.9 percent of the fishing pressure and 70.8 percent of the harvest. Bream fishermen exerted 4.9 percent of the total fishing pressure but yielded 26.0 percent of the harvest. Black crappie, catfish, golden shiner, and chain pickerel fisheries were relatively insignificant.

Overall, the catch rate on Lake Conway was 0.20 fish per man-hour. The catch rate for golden shiner (13.33 fish/man-hour) is misleading in that only one shiner fisherman was creeled, who by the way, caught 2 individuals in 15 min. Bream fishermen had a catch rate of 1.05 fish per man-hour, whereas bass fishermen collected 0.15 fish per man-hour.

Table 13
Preliminary Creel Census Results for Lake Conway from July Through September 1976

Species	Relative Effort, %	Relative Harvest, %	Catch Per Man-Hour*
Largemouth bass	94.9	70.8	0.15
Bream**	4.9	26.0	1.05
Black crappie	0.4	0.0	0.00
Catfish	0.1	0.0	0.00
Golden shiner	0.1	0.7	13.33
Chain pickerel	0.0	2.5	—
Overall			0.20

* Species directed catch rates.
** Includes bluegill, redear sunfish, warmouth, and spotted sunfish.

DISCUSSION

Insofar as we have only 3 complete months of data, we concur that, at this time, we cannot elaborate on fish population and sport fishery characteristics, nor can comparisons with other central Florida lakes be made. However, in view of the above limitations, a few preliminary statements minus lengthy discussions can be made:

a. According to species diversity analysis, the fish populations appear to be fairly stable.

b. Data generated from methods sampling shoreline vegetation reflect a higher species diversity but lower numerical abundance than data collected in shallow, nonvegetated habitats.

c. Fairly large numbers of game fish are found, but the population structure of bluegill and redear sunfish reflect an overcrowded situation, with harvestable fish of bluegill, redear sunfish, and largemouth bass being in poor condition.

d. The overall catch rate by fishermen can be considered low, although the predominance of bass fishermen on Lake Conway and their associated low catch rates may account for the low overall rates.

We feel that, with additional data from this project, an excellent biological picture of the community relationships, such as species assemblages present, species abundance, and diversity, will be realized.

Despite a recent proliferation of fishery studies in central Florida lakes, little more than a cursory appreciation of gross population dynamics has been identified. In addition to helping satisfy academic voids, Lake Conway baseline data will be important for assessing environmental changes — in this case, introduction of grass carp and its associated habitat alterations.

ACKNOWLEDGMENTS

We would like to extend our appreciation to our two fish management specialists, Dale Jones and Mike Rebel, whose efforts made this paper possible.

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AQUATIC MACROPHYTE SAMPLING IN LAKE CONWAY

by

L. E. Nall, M. J. Mahler, and J. Schardt*

INTRODUCTION

The Florida Department of Natural Resources, in cooperation with the U. S. Army Corps of Engineers, is responsible for the aquatic macrophyte sampling portion of the Large-Scale Operations Management Test with the White Amur, *Ctenopharyngodon idella*, in Lake Conway, Orlando, Florida.

As of October 1976, the fourth month of sampling is under way. Because of engineering delays in the biomass sampling boat, very little biomass information has been obtained. Since very little data have been collected, most of the following remarks will concern the sampling methodology.

OBJECTIVES

The object of this study is to show changes, if any, in the distribution, biomass, species composition, and condition of each plant species in Lake Conway. From this we hope to observe: (a) food preference of the amur, (b) rate of removal of target species, (c) effect on desirable plant species, such as eelgrass (*Vallisneria americana* Michx.) and nitella (*Nitella megacarpa* L.), and (d) interspecific competition between plant species while under stress from the amur.

METHODS AND MATERIALS

Study Site

Lake Conway is a 737.1-ha lake (Figure 1) located in south Orlando, Florida. The lake is divided into five interconnected pools consisting of Lake Gatlin, Little Lake Conway (East and West Pools), and Lake Conway (North and South Pools). Lake Conway is an urban lake typical of central Florida. The natural shoreline vegetation of cattail (*Typha latifolia* L.), maidencane (*Panicum hemitomon* Schult.), and torpedo grass (*Panicum repens* L.) has been removed around much of the lake. Illinois pondweed (*Potamogeton illinoensis* Morong.), nitella, and hydrilla (*Hydrilla verticillata* Royle) are the dominant aquatic species. Pondweed and, to a lesser extent, hydrilla are problems in parts of the lake.

Transects

Each month 20 transects (Figure 2) are sampled at 100-m intervals, which yields about 200 samples. Each sample is separated to species, weighed, dried, and weighed again. Reproductive structures, if any, are noted.

Plots

Eighteen permanently marked 1-ha plots (Figure 2) are located in representative areas of the lake.

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Figure 1. Lake Conway

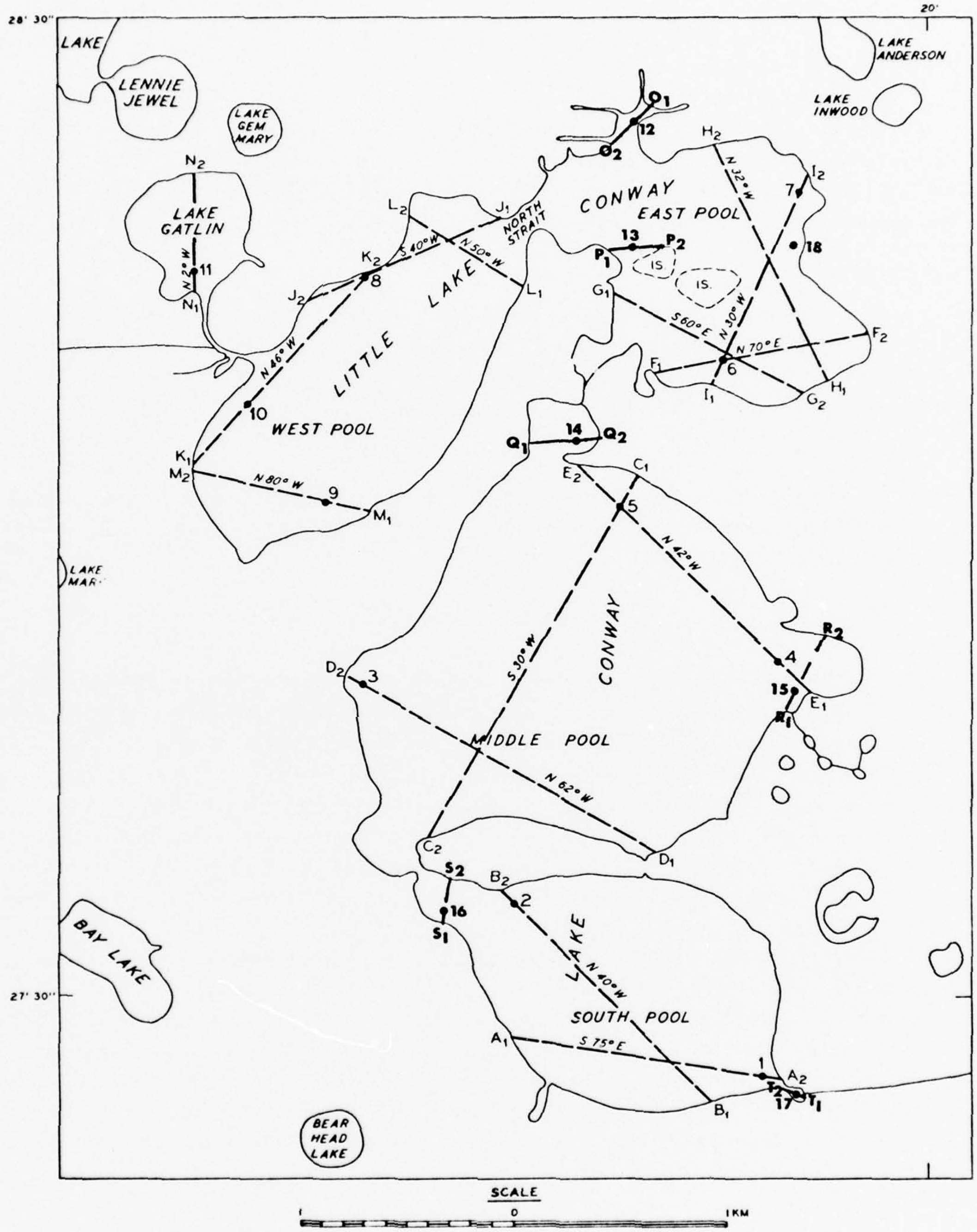

Figure 2. Vegetation transects and permanent plots

Figure 3 shows a representative plot. Two vegetation heights are measured at exactly the same points each month. Two random areas are selected and a 0.25-m square of vegetation is hand-removed by a diver. From this square the number of rooted stems are counted; the internodal lengths, stem lengths, and height from the bottom are measured; and wet and dry weights are recorded. Two biomass samples using the sampler are taken adjacent to each square.

Often vegetation is not erect (Figure 4); tops of some plants are sampled while stems and bottoms of other plants are also collected using the biomass sampling device. This could affect the accuracy of the sample. Theoretically, a diver using the square could cut the vegetation at bottom level, thus collecting only the plants actually in the square and yielding a more accurate sample. Comparison of these two methods and others, if available, will determine the accuracy of our sampling tools.

Exclosures

Several 5- by 5-m exclosures will be placed in heavily vegetated areas. These areas should visually show the effect of the amur around the structure, while offering an untouched control area inside. One random 0.25-m square will be taken monthly in each exclosure. They will also be monitored photographically.

Vegetation Maps

Quarterly vegetation maps will be prepared. Marginal and surfacing submergent vegetation will be recorded. This should show gross changes in vegetation distribution as well as provide ground truth for periodic aerial photography.

PRELIMINARY RESULTS

Forty-five species of aquatic plants (Table 1) have been identified from Lake Conway. Table 2 shows the percent occurrence along the transects of each species. Nitella and Illinois pondweed are the most frequently encountered plants in the lake. Nitella is abundant in the Middle Pool and common in the East and West Pools. Pondweed is most abundant in the East Pool but is common in all other pools except Lake Gatlin. Hydrilla is the third most frequent plant. Hydrilla is common throughout the lake except in the Middle Pool, where it is rare. Eelgrass is the only other common submerged plant in the lake. It is abundant only in the East Pool. Important emersed species are torpedo grass, maidencane, marsh pennywort (*Hydrocotyle umbellata* L.), cattail, and waterhyacinth (*Eichhornia crassipes* Mart. Solms).

East Pool is the most vegetated area in the lake. This area has only about 32 percent unvegetated area, while all other pools exceed 45 percent unvegetated area.

In wet weight, nitella is by far the most dominant plant in the lake (Table 3). The maximum weight found for a square-metre plot was 39,554.4 g. Such a plot may have almost 11,000 plants. Pondweed and hydrilla are second most abundant, averaging 120.4 g/m^2 and 61.3 g/m^2, respectively. Vallisneria ranks fourth with 56.6 g/m^2. Maximum weights per square metre for pondweed, hydrilla, and eelgrass are 2780.0 g, 3760.0 g, and 2057.0 g, respectively. These plants may have 300, 2500, and 1800 stems per square metre, respectively.

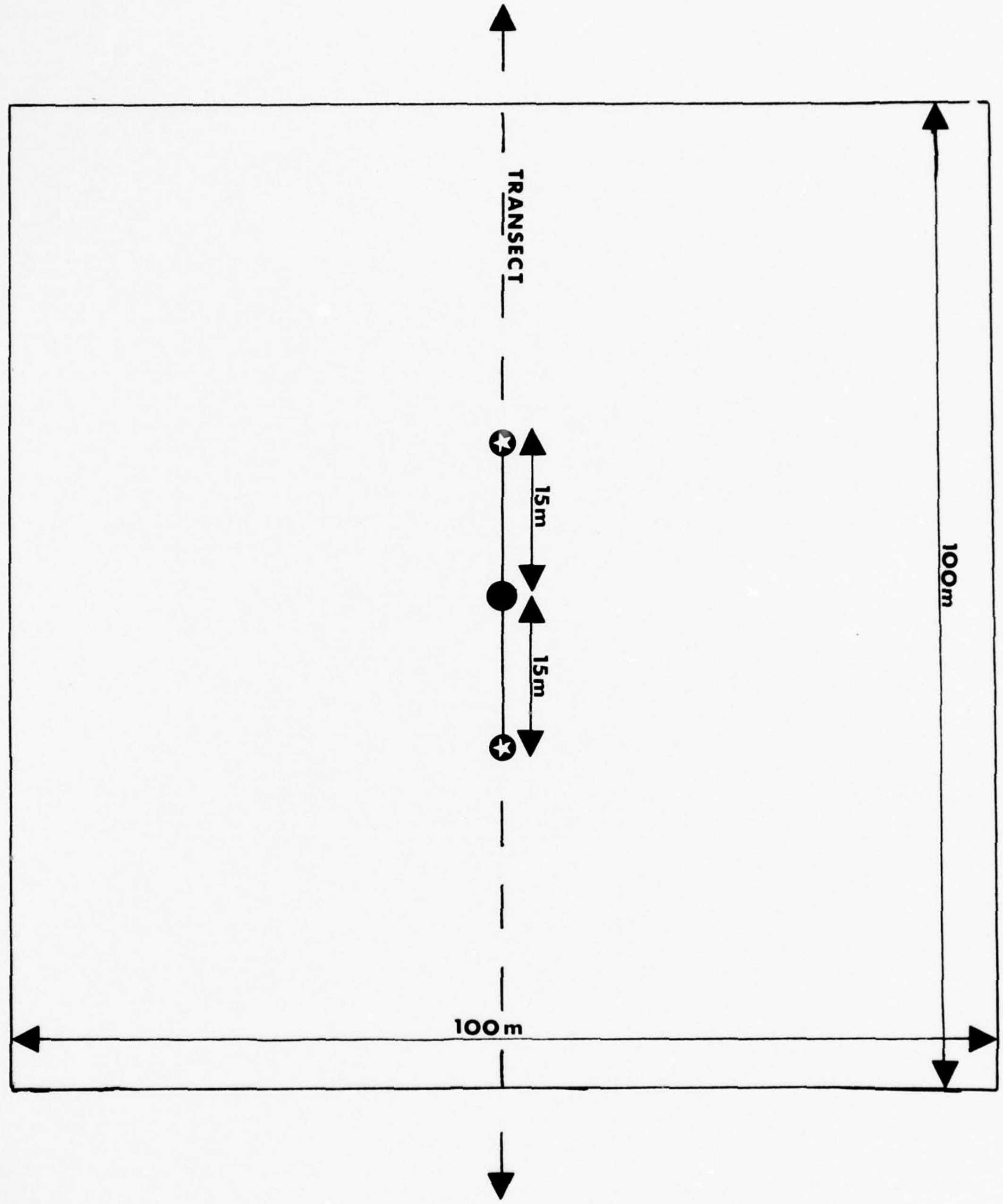

Figure 3. Typical permanent plot

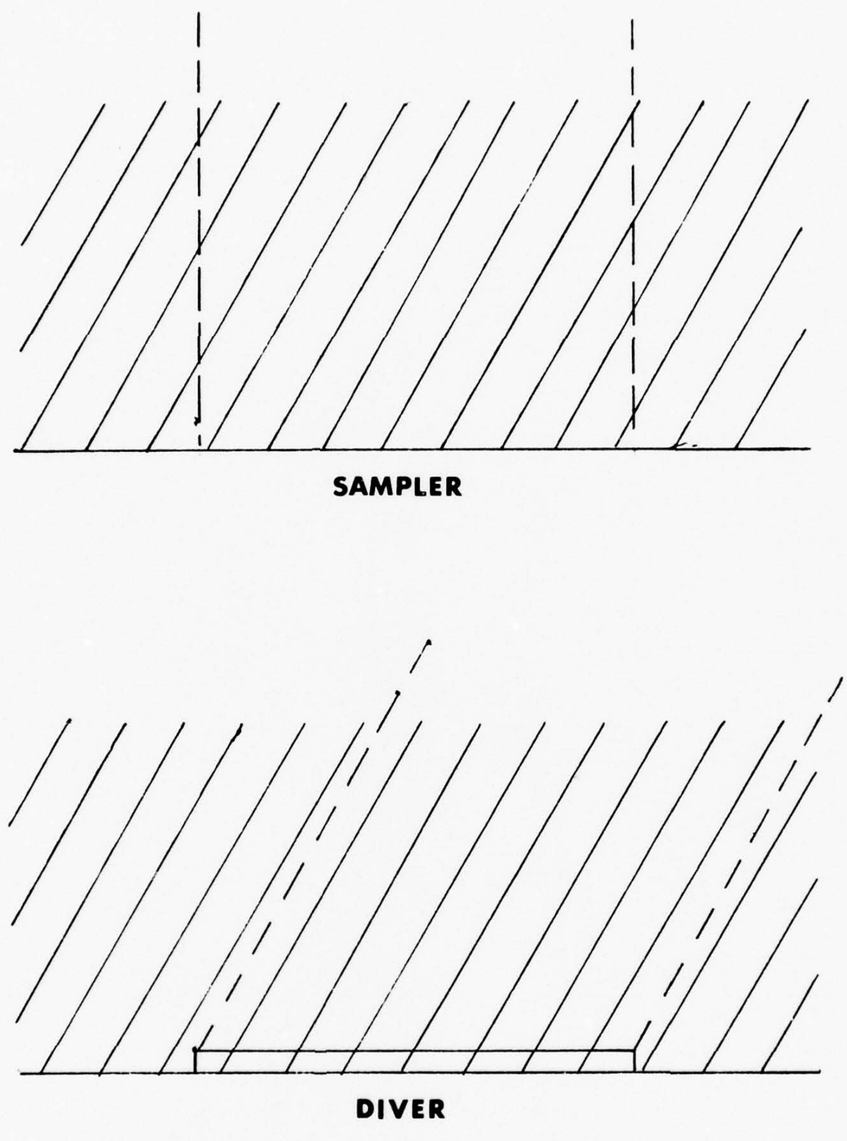

Figure 4. Schematic diagram comparing sampler and diver sampling methods

Table 1
Flora of Lake Conway

Bacopa caroliniana	Waterhysop
Bacopa monneri	Lemon bacopa waterhysop
Bidens bipinnata	Water beggars tick
Cabomba aquatica	Giant fanwort
Ceratophyllum demersum	Coontail
Cladium jamaicensis	Sawgrass
Colacasia antiquorum	Elephant ears
Cyperus papyrus	Papyrus sedge
C. strigosus	
Eichhornia crassipes	Waterhyacinth
Eleocharis acicularis	Slender spikerush
E. baldwinii	Hairgrass
Eupatorium capillifolium	
Fuirena scirpoides	Lake rush
Habenaria repens	Water orchid
Hydrilla verticillata	Hydrilla
Hydrocotyle umbellata	Pennywort
H. verticulatus	Pennywort
Hypericum percoliatum	
Ludwigia octavalis	Primrose willow
L. palustrus	Primrose willow
L. peruviana	Marsh purslane
Mayaca fluviatilia	Bogmoss
Myriophyllum brasiliense	Parrotfeather
Najas flexilis	Slender naiad
Nitella megacarpa	Nitella
Nuphar macrophyllum	Spatterdock
Nymphae odorata	Fragrant waterlily
Panicum hemitomon	Maidencane
P. purpurescens	Paragrass
P. repens	Torpedo grass
Pluchea sp.	Fleabane
Pontederia cordata	Pickerelweed
P. latifolia	Pickerelweed
Potamogeton illinoensis	Illinois pondweed
P. puscillus	Slender pondweed
Salvinia rotundifolia	Salvinia
Sagittaria lancifolia	Arrowhead
S. subulata	Dwarf arrowhead
Typha latifolia	Cattail
Utricularia fibrosa	Fibrous bladderwort
U. foliosa	Leafy bladderwort
U. inflata	Big floating bladderwort
U. purpurea	Purple bladderwort
Vallisneria americana	Eelgrass

Table 2

Monthly Species Composition Averages of Plants Found Along Transects

Plant	Total	South	Middle	East	West	Gatlin
			Number of Stations			
	202*	37	66	52	40	7
	194**	34	63	51	39	7
	197†	35	63	52	40	7
			Percent Without Vegetation			
	40.1	45.0	40.9	28.8	45.0	57.1
	42.3	44.1	42.9	31.4	53.8	42.6
	47.7	45.7	52.4	36.5	55.0	57.1
			Percent Species Composition			
Submersed						
Nitella megacarpa	22.3	18.9	34.8	21.2	10.0	--
	24.2	20.6	33.3	27.5	10.3	14.3
	17.7	14.3	28.6	15.4	10.0	--
Potamogeton illinoensis	21.8	16.2	22.7	28.8	20.0	--
	20.6	8.8	25.4	33.3	10.3	--
	23.9	22.9	22.2	30.8	22.5	--
Hydrilla verticillata	18.3	27.0	1.5	23.1	32.5	14.2
	18.6	23.5	4.8	31.4	20.5	14.3
	12.7	20.0	4.8	15.4	15.0	14.2
Vallisneria americana	7.9	--	--	25.0	7.5	--
	11.3	--	--	33.3	10.3	14.3
	10.2	--	1.6	30.8	7.5	--
Utricularia inflata	1.0	--	1.5	1.9	--	--
	2.1	--	6.3	--	--	--
	--	--	--	--	--	--
Ceratophyllum demersum	0.5	--	1.5	--	--	--
	0.5	--	1.6	--	--	--
	0.5	--	1.6	--	--	--
Eleocharis baldwinii	1.0	--	1.5	--	--	14.2
	0.5	--	--	--	--	14.2
	--	--	--	--	--	--
Najas flexilis	--	--	--	--	--	--
	--	--	--	--	--	--
	0.5	--	--	--	--	14.2
Bacopa monneri	0.5	2.7	--	--	--	--
	--	--	--	--	--	--
	--	--	--	--	--	--
Emersed						
Panicum repens	10.4	16.2	3.0	7.7	17.5	28.6
	10.8	17.6	6.3	7.8	12.8	28.6
	9.6	14.3	4.8	5.7	15.0	--

(Continued)

* July.
** August.
† September.

Table 2 (Concluded)

Plant	Total	South	Middle	East	West	Gatlin
	Percent Species Composition (Continued)					
Emersed (Continued)						
Panicum hemitomon	4.9	10.8	3.8	7.5	--	--
	5.2	8.8	1.6	3.9	10.3	--
	9.6	14.3	4.8	5.7	15.0	--
Pontederia latifolia	1.5	2.7	1.5	1.9	--	--
	1.5	5.8	--	2.0	--	--
	0.5	--	--	1.9	--	--
Typha latifolia	4.5	--	3.0	11.5	2.5	--
	4.6	--	4.8	9.8	2.6	--
	0.5	--	--	1.9	--	--
Fuirena scirpoides	2.0	8.1	1.5	--	--	--
	2.6	5.8	3.2	--	2.6	--
	1.0	2.9	--	--	2.5	--
Sagittaria lancifolia	0.5	--	--	--	2.5	--
	0.5	--	--	--	2.6	--
	--	--	--	--	--	--
Nymphae odorata	1.5	--	--	3.8	2.5	--
	0.5	--	--	1.9	--	--
	0.5	--	--	1.9	--	--
Hydrocotyle	5.9	10.8	3.0	3.8	10.0	--
	6.7	8.8	1.6	5.9	10.3	28.6
	0.5	--	--	--	--	14.2
Ludwigia octavalis	1.5	2.7	1.5	1.9	--	--
	0.5	--	--	2.0	--	--
	--	--	--	--	--	--
Cyperus spp.	2.0	2.7	1.5	--	2.5	14.2
	2.1	2.9	--	--	5.1	14.3
	--	--	--	--	--	--
Colacasia antiquorum	--	--	--	--	--	--
	0.5	--	--	--	--	14.3
	--	--	--	--	--	--
Panicum purpurescens	--	--	--	--	--	--
	--	--	--	--	--	--
	0.5	--	--	--	2.5	--
Eichhornia crassipes	5.9	8.1	1.5	9.6	5.0	14.2
	5.7	8.8	1.6	9.8	5.1	--
	1.5	5.7	--	--	2.5	--

Table 3
Fresh Biomass of Plants Along Transects

Plant	N*	$\bar{X}$, g**	Nv†	$\bar{X}$v, g††	Maximum Weight g/m^2
Gatlin					
Hydrilla	7	2.1	1	14.8	14.8
East					
Potamogeton	51	289.6	18	820.5	2,780.0
Nitella	51	328.6	11	1523.4	4,284.0
Hydrilla	51	32.9	5	335.6	1,170.0
Vallisneria	51	142.4	17	727.2	2,057.0
West					
Potamogeton	40	72.0	9	320.2	978.4
Nitella	40	305.9	4	3059.1	4,514.0
Hydrilla	40	66.6	6	444.0	1,720.8
Vallisneria	40	47.8	4	477.6	1,153.2
Middle					
Potamogeton	63	80.5	14	362.4	1,224.0
Nitella	63	2930.4	19	9716.7	36,722.0
Hydrilla	63	2.2	5	27.8	62.4
Ceratophyllum	63	23.8	1	1496.4	1,496.4
Vallisneria	63	30.5	1	1920.0	1,920.0
South					
Potamogeton	35	24.8	8	108.4	490.4
Nitella	35	1685.9	7	8429.9	39,554.4
Hydrilla	35	214.6	8	938.8	3,760.0
Total					
Potamogeton	196	120.4	49	481.5	2,780.0
Hydrilla	196	61.3	25	480.6	3,760.0
Nitella	196	1390.9	41	6649.3	39,554.4
Ceratophyllum	196	7.6	1	1496.4	1,495.4
Vallisneria	196	56.6	22	504.2	2,057.0

* Number of sampling stations.
** Average biomass for all stations.
† Number of stations where each species was encountered.
†† Average biomass at stations where each species was encountered.

BIOLOGICAL BASELINE STUDIES OF THE LAKE CONWAY, FLORIDA, SYSTEM

by

J. L. Fox, E. C. Blancher, F. M. Kooijman,
R. A. Conley, and C. P. Feerick*

INTRODUCTION

As part of its national aquatic weed research program, the U. S. Army Corps of Engineers plans to introduce the white amur (*Ctenopharyngodon idella*) into Lake Conway, a 735-ha lake system near Orlando, Florida. In order to evaluate the effects of the introduction, county and state agencies, as well as groups within the University of Florida, have been contracted to provide baseline and post-introduction data to the Corps.

Since April 1976, the Department of Environmental Engineering Sciences at the University of Florida has been monitoring a number of biological and physiocochemical parameters in the Lake Conway system. The major objective of our research is the evaluation of the effect of the fish upon the zooplankton, the phytoplankton, and the benthic invertebrate community. Our methodology and baseline results to date follow. Also included is a brief discussion of some additional activities presently under way or anticipated.

ZOOPLANKTON

Methods

Zooplankton was collected from the stations shown in Figure 1 using two techniques. The first consisted of lowering a weighted No. 10 (153μ mesh size) plankton net to slightly above the bottom and returning it to the surface. The organisms were rinsed from the collection bucket into 2-oz sampling bottles and preserved with alcohol. This method provides data that allow a comparison of zooplankton populations on an areal (per square metre) or a volumetric (per cubic metre) basis. Vertical hauls were taken at all stations. At the deep stations (Nos. 4, 7, 6, 18, and 20), a gasoline-powered centrifugal pump was used to obtain zooplankton from desired depths. Twenty litres of water were pumped from each metre interval into a No. 10 plankton net and collected as described above. This technique allows us to compare zooplankton populations at the various depths on a volumetric basis.

In the laboratory, the concentrated zooplankton sample was placed in a shallow covered dish and counted and identified using a stereoscopic dissecting microscope at a magnification of 50 diameters. The keys of Edmonson[1] and Pennak[2] were used for identifications.

Results and Discussion

With one exception, the results presented here were obtained by vertical plankton tows from all stations. Six copepod, nine cladocera, and ten rotifer species were collected from April through August 1976. Table 1 shows the species thus far identified. Total zooplankton abundance and relative

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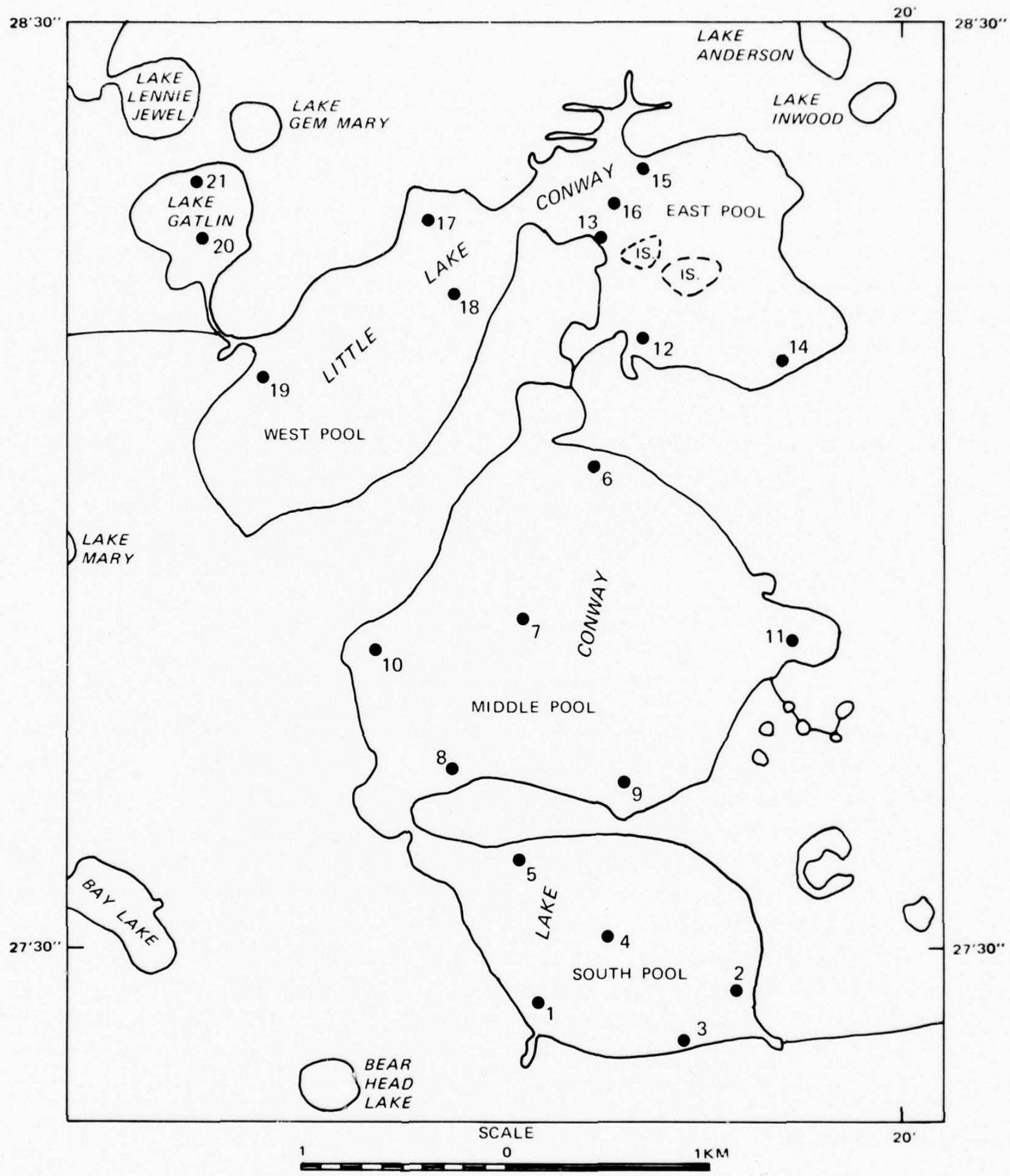

Figure 1. Map of Lake Conway system showing sampling stations for phytoplankton, zooplankton, benthic invertebrates, and water chemistry

Table 1
Species List of Zooplankton Occurring in Lakes Conway and Gatlin

Family	Scientific Name
Copepoda	*Diaptomus floridanus*
	Cyclops varicans
	Cyclops bicuspidatus
	Tropocyclops prasinus
	Ergasilis sp.
	Unidentified sp. A. (Harpacticoid)
Cladocera	*Alona* sp.
	Bosmina longirostris
	Camptocercus retrirostris
	Ceriodaphnia reticulata
	Chydorus sphaericus
	Daphnia ambigua
	Diaphanosoma brachyurum
	Macrothrix hisurtocornis
	Pleurexus sp.
Rotifera	*Asplanchna* sp.
	Brachionus sp.
	Conchilus unicornis
	Enteroplea lacustris
	Kellicottia sp.
	Keratella cochlearis
	Lecane sp.
	Monostyla sp.
	Platyias patulus
	Trichocerca sp.

abundance are shown in Figures 2 and 3, respectively. Both composition and abundance are in agreement with published values for Florida (Nordlie[3] and Cowell, Dye, and Adams[4]) and North America (Pennak[5]).

Diaptomus floridanus, a large calanoid, was the dominant copepod until August, when two species of cyclopoid species, *Cyclops varicans* and *Tropocyclops prasinus*, replaced it (Figure 4). These three species comprised over 95 percent of the copepods collected. Nauplii, which are larval forms of copepods, were abundant in April and August but represented only 1 percent of the total population in July. This change can be attributed to both the normal seasonal fluctuations of copepod populations

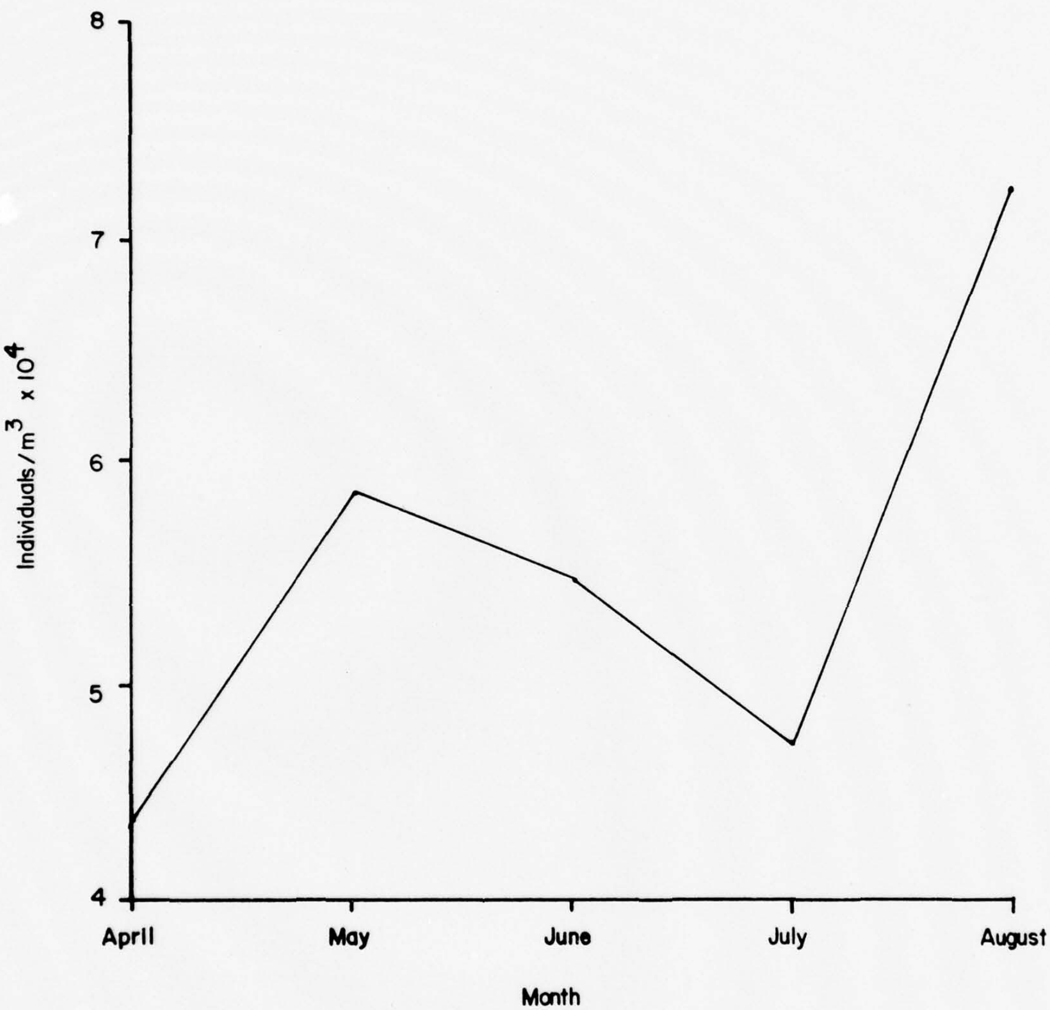

Figure 2. Total zooplankton abundance for all pools (vertical hauls)

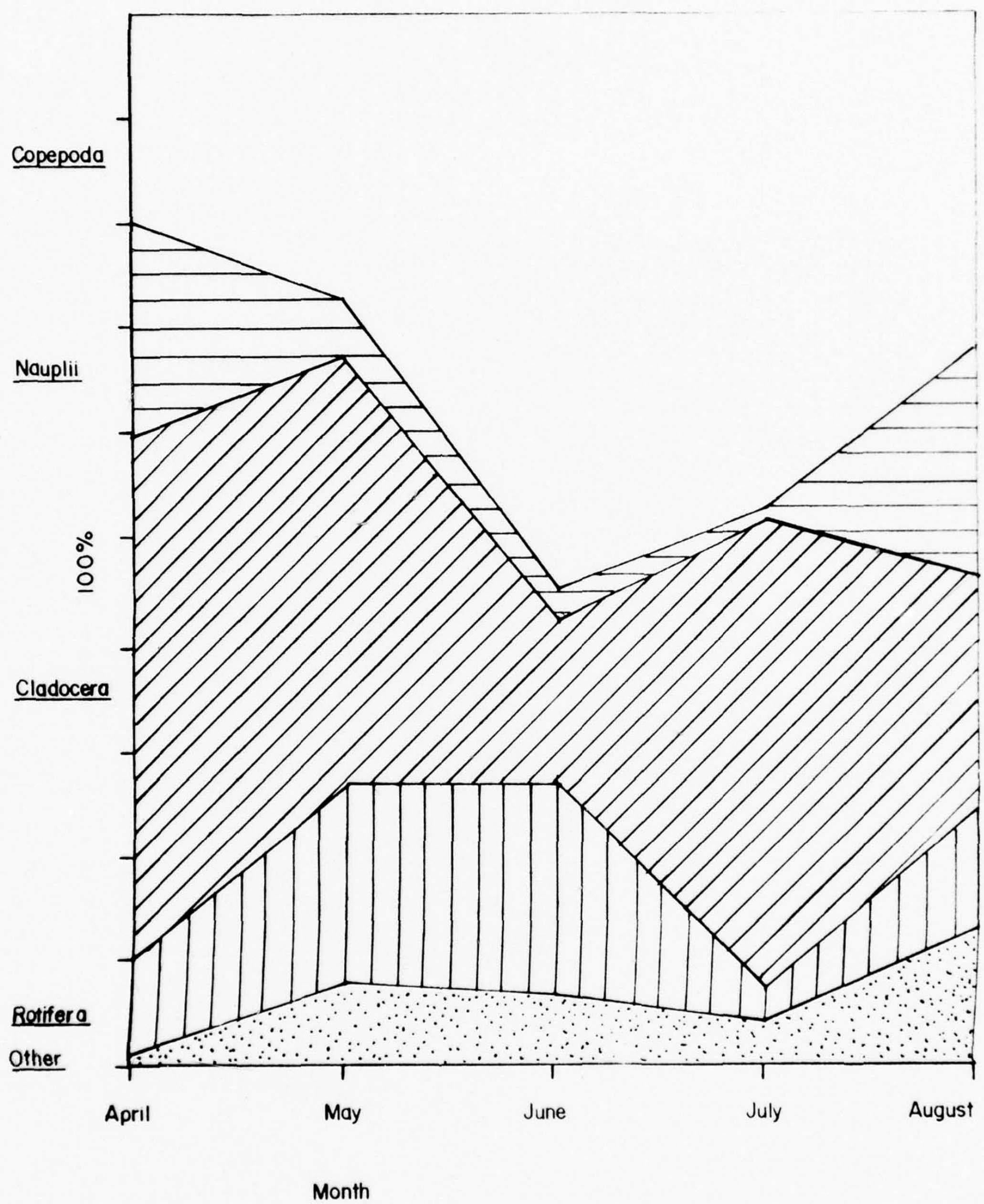

Figure 3. Relative abundance of zooplankton in Lake Conway from April through August 1976 (vertical hauls)

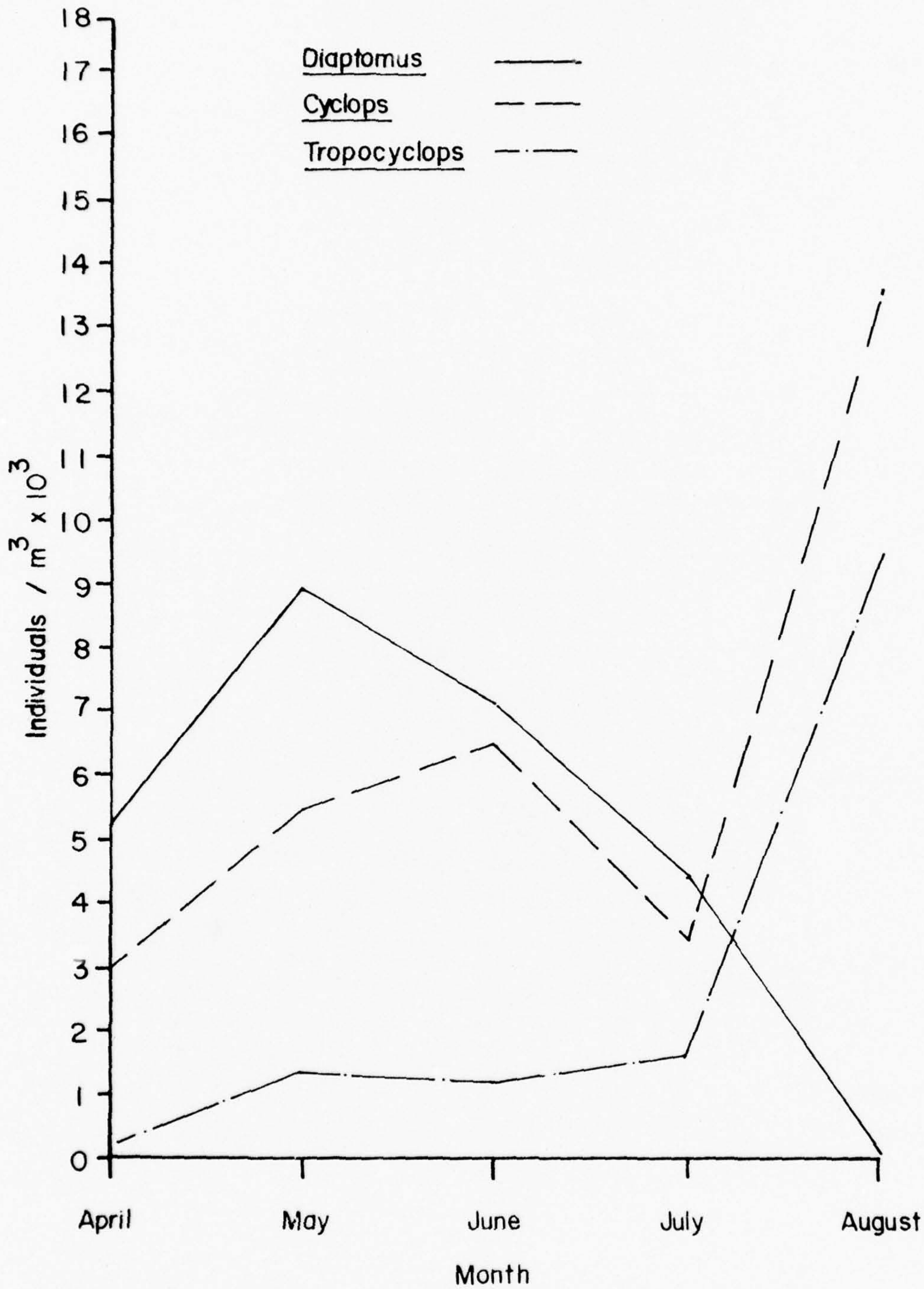

Figure 4. Abundance of major copepoda in Lake Conway, April through August 1976

and the fact that very small nauplii may pass through the net. To avoid this problem in the future, we are now using a No. 20 net (80μ mesh) in addition to the No. 10 net at all deep stations.

The three dominant forms of cladocera found in Lake Conway were *Bosmina longirostris*, *Ceriodaphnia reticulata*, and *Diaphanosoma brachyurum* (Figure 5). All are well known limnetic species in Florida lakes (Nordlie[3]). In contrast to the copepods, which may live for a year or longer, cladocera live for shorter periods (1 to 2 months). Thus, several population maxima may occur during the year. Variations between monocycly, dicycly, or acycly depend on both species present and environmental variables.

In Lake Conway, the major rotifer present demonstrated short vernal peaks, typical of these small animals. Figure 6 illustrates the shift in rotifer abundance from April through August. Major species were *Keratella cochlearis*, *Asplanchna* sp., *Conchilus unicornis*, and *Platyias patulus*.

Figure 7 depicts a typical vertical distribution of two zooplankton genera, *Diaptomus* and *Bosmina*. Results to date have not provided sufficient information to establish trends in the vertical distribution of zooplankton.

A zooplankton community at any point in time represents a compromise between conflicting demands of individual species and the optimal allocation of all available resources. Generally, opportunistic species with high rates of increase are favored in highly changing environments while others, which possess other competitive abilities, are favored in more constant environments (Alan[6]). Usually both types of species are represented in a balanced freshwater community.

Rotifers and cladocerans have short life cycles, are rather unspecialized feeders, and develop large transitory populations. Copepods, on the other hand, exhibit longer life cycles and have fewer generations. All groups are well represented in Lake Conway at the present time. Biotic changes in the lake that affect either the feeding habits of the zooplankton or predation pressure will have an effect on this community. An increase in organic or nutrient loading in the lake and selected feeding by fish would favor the selection of small-bodied herbivores (rotifers and small-bodied cladocera). Large increases in these groups with a corresponding decrease or disappearance of other species would indicate undesirable changes. However, careful interpretation is necessary in light of the fact that year-to-year replacement of species may occur in normal unstressed communities. Future observations will focus on these possibilities.

PHYTOPLANKTON

Methods

One-litre phytoplankton samples and 300-millilitre samples for chlorophyll were collected monthly (April through August) from 21 locations in the pools of Lake Conway (Figure 1). From the deep stations near the pool centers, samples were taken from 1 m, middepth, and from within 1 m of the bottom. All littoral-zone samples were taken from a depth of 1 m. Chlorophyll samples were immediately placed in a dark cooler and kept on ice until filtered and acetone extracted. Filtration generally occurred within 2 days. Chlorophyll *a* concentration was determined spectrophotometrically using the phaeophytin correction technique as described by the Environmental Protection Agency.[7] Phytoplankton samples were preserved with neutralized formalin. The algae were concentrated by settling and decanting to a final volume of 20 to 40 ml. Identification and counts were made using a Unitron inverted microscope with a modified Sedgewick-Rafter chamber inverted on the stage. Counting was done at a magnification of 200 to 400 diameters although the use of a No. 2 coverslip

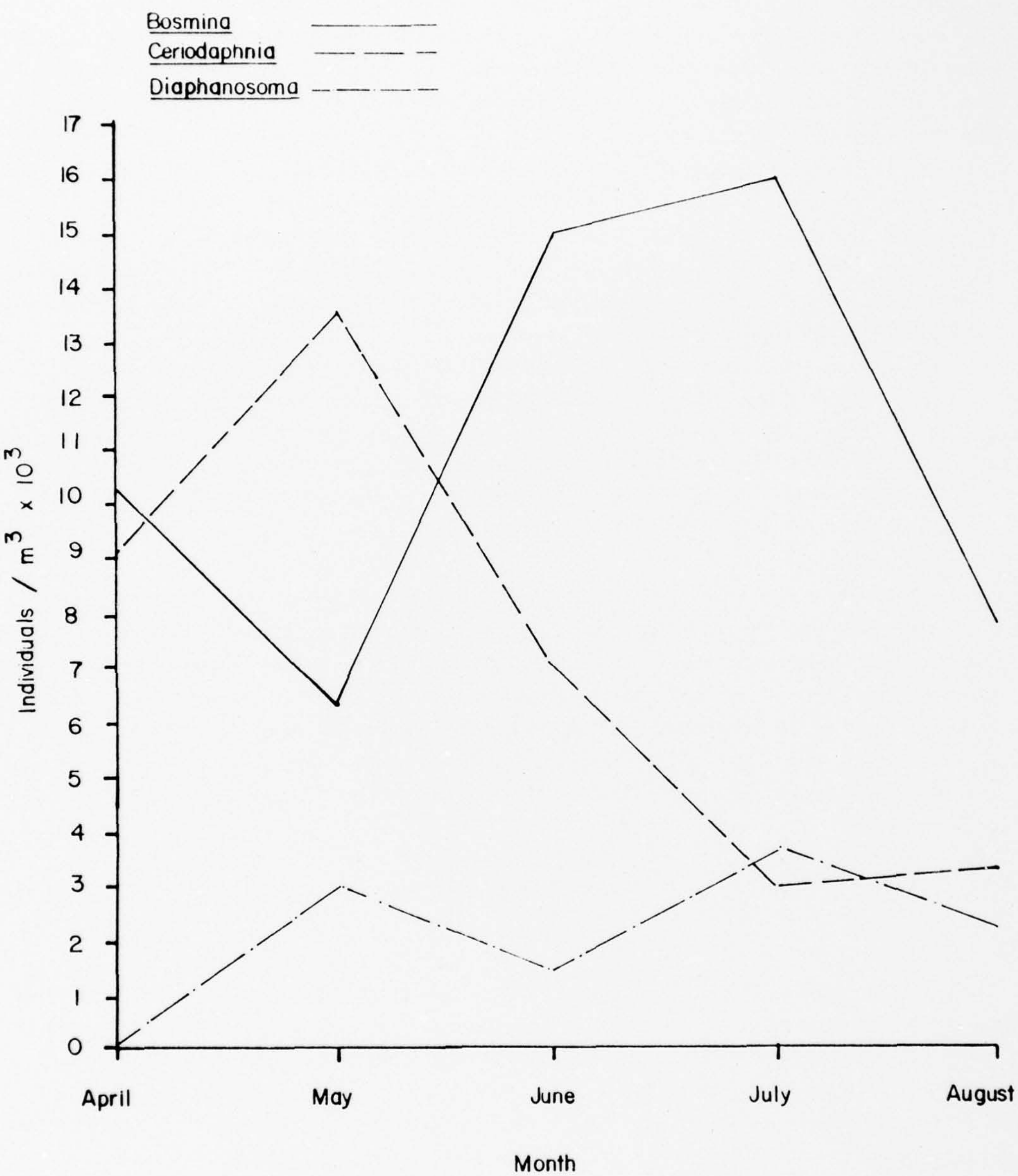

Figure 5. Abundance of major cladocera in Lake Conway, April through August 1976

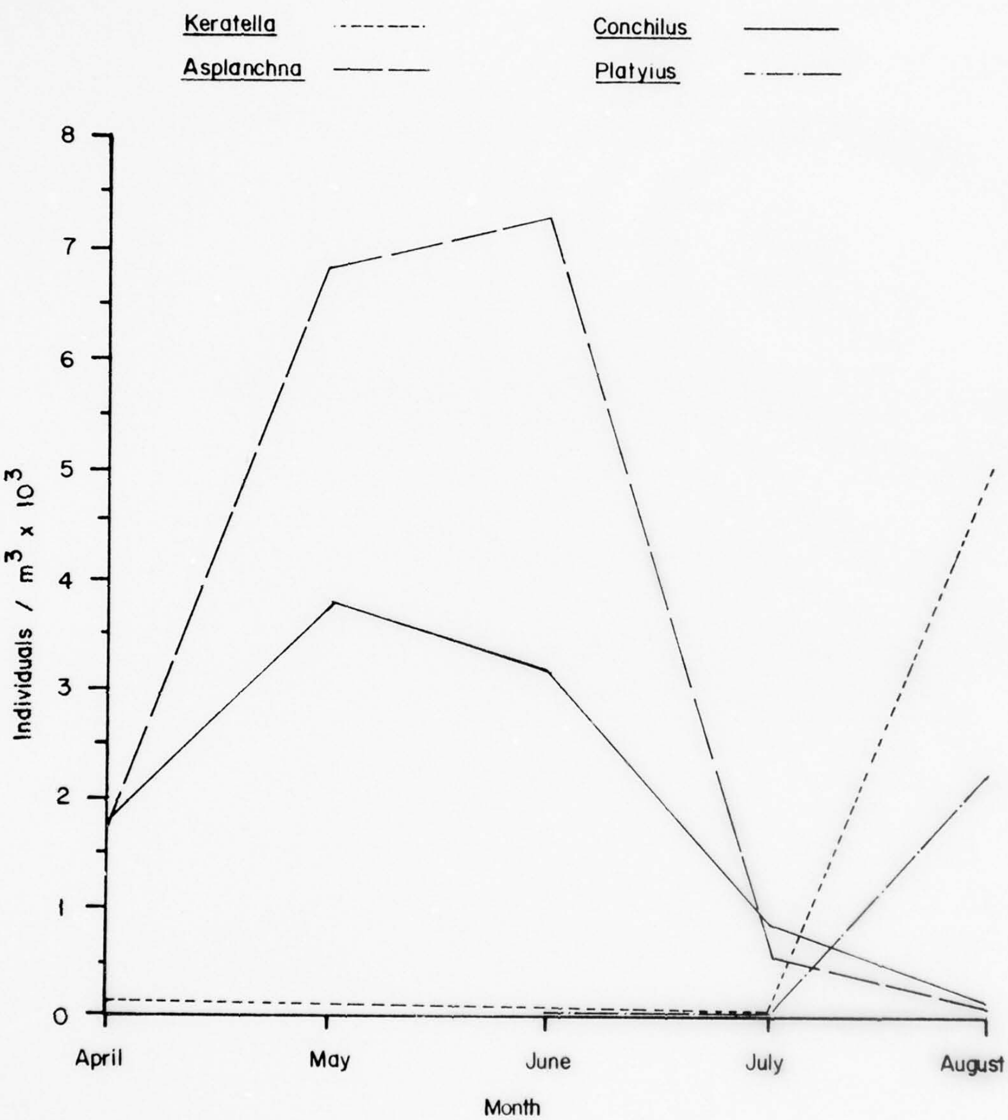

Figure 6. Abundance of major rotifera in Lake Conway, April through August 1976 (vertical hauls)

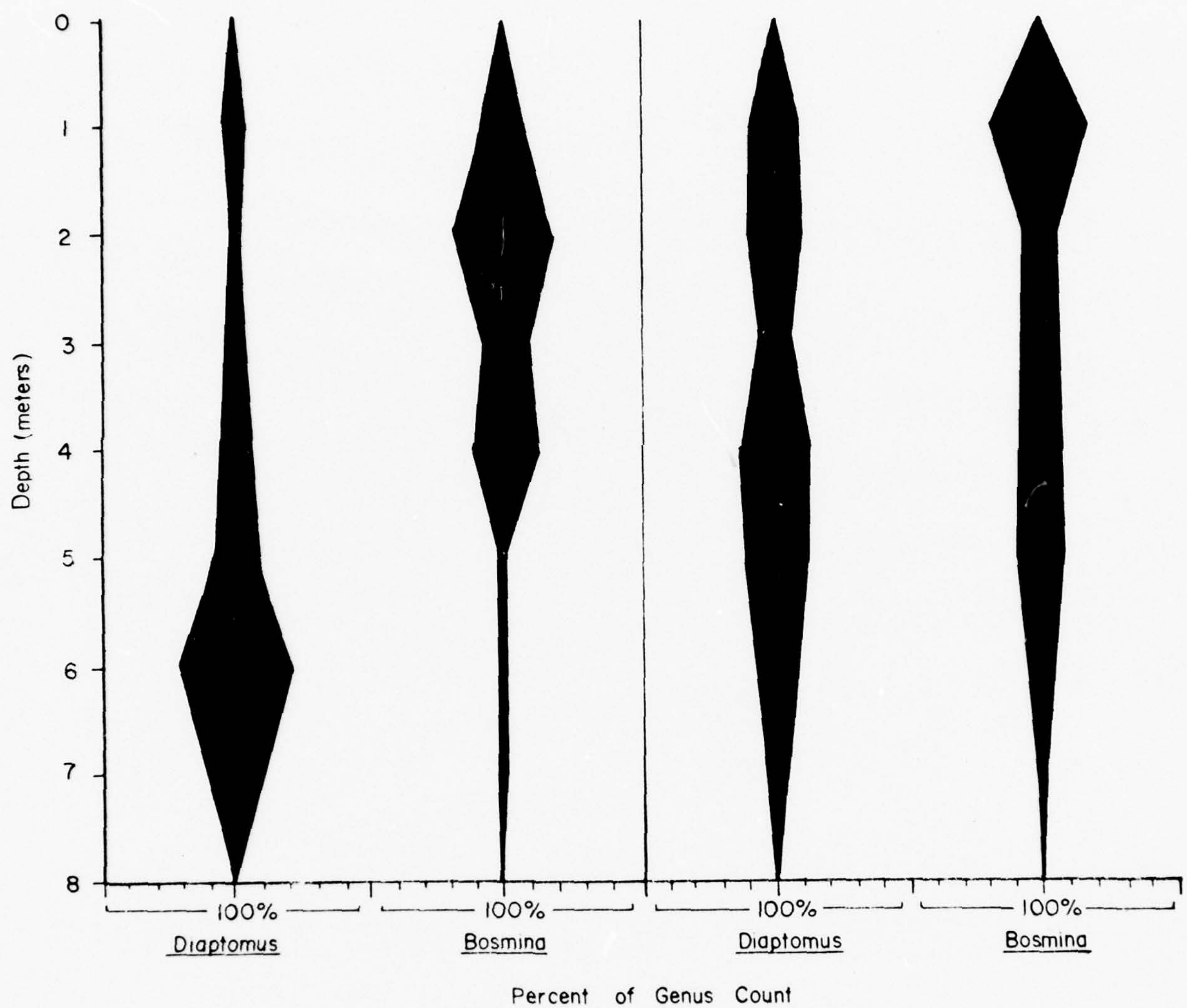

Figure 7. Representative vertical distribution of *Diaptomus* and *Bosmina* in Lake Conway in May 1976

allows the use of higher magnifications for identification. For diatom identification, permanent mounts were made by clearing the organisms with 30 percent hydrogen peroxide and mounting in permount.

Results

The phytoplankton in Lake Conway is diverse with many species of green (chlorophyta) and blue-green (cyanophyta) algae. A typical count of 200 to 400 cells shows 25 to 30 species present. Generally, the most abundant species comprises 20 to 40 percent of the total. The algal densities from the centers of each pool (sampled at 1 m) are shown in Table 2. Abundances increased from around 500 cells/ml to 10,000 cells/ml from April to July, followed by a decline in August. Chlorophyll *a* concentration shows the same increasing trend from April to September. However, August values for chlorophyll *a* were not obtained so that no decline was noted between July and September. The four pools of Lake Conway tend to be similar in algal density while Lake Gatlin is higher. It is difficult to summarize differences between pools because all samples have not been analyzed and there appear to be large differences between stations in some pools.

Table 2
Algal Concentrations (cells/ml) in Pool Centers*

	April	May	June	July	August
South	195	2610	5000	7,780	5050
Middle	760	1980	5190	10,300	5710
East	702	3270	5100	7,990	4600
West	290	1880	6160	5,570	6300
Gatlin	720	2460	5840	10,800	8480
Average	533	2440	5460	8,490	6070

* Samples taken at 1 m.

The Shannon-Weaver diversity index for the phytoplankton is rather constant at 3.5 to 4.0. Shifts in relative abundance occur, but the species present remain fairly constant. In general, blue-green algae are most abundant with many species of green algae also present. Diatoms are present in greatest numbers in the spring. The patterns of shifting relative abundance appear complex and require analysis of more samples to be understood. Table 3 presents a list of species encountered thus far.

Data on vertical distribution are shown in Table 4. Depth profiles were not available for April. In May, the algal density was highest at middepth. From June to August, however, the concentration drops from top to bottom. The peak surface density in July corresponded with the greatest difference between surface and deeper water samples. During periods of low algal abundance, the density should be fairly uniform throughout the water column since light can penetrate to the bottom. When algal populations are high, shading of lower levels occurs, and the greatest productivity and largest concentrations of algae will be found in the surface waters.

The chlorophyll and algal counts indicate that Lake Conway is a mesotrophic lake. Algal counts of less than 200 to 300/ml are indicative of oligotrophic conditions. The density in Lake Conway was near this level during April and could be lower during the winter months. The maximum concentration encountered thus far at a deepwater station is 10,800 cells/ml, which is below the 20,000 or above

Table 3
Partial List of Phytoplankton Species Present in Lake Conway
April Through August 1976

Frequent or Occasionally Abundant	Common	Occasional to Rare
Anabaena cf. *wisconsinense*	*Tetraedron minimum*	*Ankistrodesmus falcatus*
cf. *Oscillatoria* sp.	*Tetraedron caudatum*	*Agmenellum* sp.
cf. *Cylindrospermum* sp.	*Scenedesmus* spp. (3)	*Aphanocapsa delicatissima*
Chroococcus limneticus	*Staurastrum* spp. (3)	*Aphanothece nidulans*
Chroococcus dispersus	*Cosmarium* sp.	*Coelastrum cambricum*
Cyclotella stelligera	*Dinobryon bavaricum*	*Coelastrum spaericum*
Cyclotella meneghiniana	*Oscillatoria* cf. *limnetica*	*Crucigenia crucifera*
Synedra sp.	*Coelosphaerium naegelianum*	*Dictyosphaerium ehrenbergianum*
Achnanthes minutissima	*Selenastrum minutum*	*Elakatothrix gelatinosa*
	Kirchneriella contorta	*Lagerheimia ciliata*
	Kirchneriella solitaria	*Lyngbya* sp.
		Microcystis aeruginosa
		Microcystis incerta
		Nitzschia palea.
		Oocyctis spp. (4)
		Mougeotia sp.
		Peridinium inconspicuum
		Euastrum sp.

Table 4
Mean Vertical Distribution of Phytoplankton in Lake Conway
April Through August 1976 (cells/ml)

Depth	April	May	June	July	August
Top (1 m)	533	2440	5460	8490	6070
Middle (3.8 m)	--	3380	4600	5740	5790
Bottom (6.8 m)	--	2390	4165	5160	4450

cells/ml which are often found in eutrophic waters. Between April and September the mean chlorophyll *a* concentration ranged from 2.5 to 9. Carlson[8] considered 6.4 mg/m^3 to be about midrange for chlorophyll *a* and indicative of mesotrophy.

The algal species present also point to mesotrophic conditions. Much of the algal biomass is blue-green (cyanophyta), which is associated with eutrophic conditions and high nutrient levels. On the other hand, most of the species present are green algae (chlorophyta). In addition, many of the chlorophytes are desmids, which are considered to be indicators of oligotrophic conditions. The desmid group has been used as the denominator in various algal species ratios that increase with increasing trophic state. A

richer desmid flora lowers the trophic index and points to more oligotrophic conditions. Thus, Lake Conway contains traditional indicators of both eutrophy and oligotrophy. As such, it is difficult to classify on the basis of phytoplankton data exclusively. In general, the lakes appear to be in good condition with little difficulty from high populations. Bloom conditions have not occurred and the water clarity is generally high. Lake Conway is quite free of algal problems, considering the heavy residential development of the shoreline and the high temperature and solar energy inputs of central Florida.

The rather high populations of macrophytes may be a partial explanation of the low algal abundance. The large populations of *Potamogeton* and *Hydrilla* may take up nutrients that otherwise would be utilized for growth by algae. More complete conclusions on the biology of Lake Conway phytoplankton will follow more complete analysis of samples in hand as well as the collection of data in the coming months. All biological systems are greatly influenced by seasonal fluctuations so that conclusions based on a few months' data must be made with a degree of caution.

BENTHIC INVERTEBRATES

Methods

Benthic invertebrate samples were collected in April, May, July, and September 1976 and will continue to be collected every 2 months. This sampling regime will adequately characterize seasonal variations in the slow-changing invertebrate populations. We selected 21 sampling stations over the four pools and Lake Gatlin. In April and May, one sample was taken at each station. In July and September, two samples were taken at each station. Duplicate samples will be taken in the future.

During the first three sampling periods, an Ekman dredge was used to obtain the samples. This dredge, lowered on a cable to the lake bottom, takes a 0.25-ft^2 (0.023-m^2) bite from the bottom. The material is brought into the boat and sieved through a U. S. Standard No. 30 sieve (0.595-mm mesh) to remove mud and sand particles. The remaining detritus and live plant material (containing the benthic invertebrates) is preserved with formalin, simultaneously vital stained with rose bengal, and stored in jars for further analysis in the laboratory. In September, the Ekman dredge was replaced by a Micro-Ponar dredge. This dredge samples the same surface area as the Ekman, and the sampling results of the two grabs are comparable. Owing to a different design, however, the Ponar does not lose any of the sample while it is being hauled up into the boat.

In the laboratory, the samples are washed to remove the formalin. The stained benthic invertebrates are then handpicked from the detritus and preserved in alcohol. Counting and identification were done using a stereoscopic or compound microscope. The organisms were identified to the species level when possible. To aid in identification, the keys of Pennak,[2] Beck,[9] and Brinkhurst[10] were used. A Shannon-Weaver diversity index was calculated for each sample using the formula suggested by EPA:[7]

$$\bar{d} = \frac{C}{N}\left(N \log_{10} N - \Sigma n_i \log_{10} n_i\right)$$

where

C = 3.23

N = total number of individuals

n_i = number of individuals of the i^{th} species

An artificial substrate sampling technique is also being used. Masonite multiple-plate samplers were constructed according to EPA[7] guidelines. These were hung in the water from docks during June and July and collected after 7 weeks. The organisms that had colonized the samplers during the incubation period were removed by hand and preserved in alcohol. In September, these samplers were hung from lines suspended between weights on the lake bottom and floats on the lake surface at five different stations (one in each pool, Figure 8). At each of the five stations, one sampler was suspended at 0.5 m and one at 1.5 m from the lake bottom with the aid of SCUBA techniques. These 10 samplers will remain in the water for 4 weeks. This procedure will be repeated at 2-month intervals.

Results

With the exception of April, all 21 stations were sampled at each sampling date. The six deep stations were omitted in April.

The total number of taxa found is presently 56, but the list is growing as more samples are being examined. Most identifications are certain to genus level, while approximately 50 percent of the taxa have been identified to species. The species list (Table 5) contains a number of common, pollution-tolerant invertebrates as well as a fairly large number of species that are more or less intolerant of environmental stress. The latter group includes species of ephemeroptera (mayflies), odonata (damselflies and dragonflies), trichoptera (caddisflies), and a few species of chironomidae (midges).

The number of species per sample varied from 3 to 22. From the data gathered in May, it was evident that the shallow-water stations supported larger and more diverse populations than the deeper sections of the lakes. Table 6 illustrates this point. This finding correlates well with our visual observations. Using SCUBA techniques, we noticed that only the shallower sections along the shoreline have dense submerged vegetation, which can support a large number of invertebrate species. In the deeper sections of the lake, the very low light levels prevent any plant growth and the bottom consists of very soft mud.

Among the more abundant species, the flatworm *Dugesia tigrina* and the snail *Goniobasis* sp. occurred only at shallow stations (along with many less abundant species). The tubificidae (sludgeworms), *Hyallela azteca* (scud), and most of the chironomidae (midge larvae) occurred evenly at deep and shallow stations. *Chaoborus albipes* (phantom midge) was found almost only at the deep stations. Not all species were distributed evenly among the five pools.

Table 7 shows some biological parameters grouped according to month and lake basin. On the average, the diversity, number of species/sample, and the density (individuals/m^2) were higher in the Middle and East Pools than in the other two pools and Lake Gatlin. In the South, Middle, and East Pools, average densities went up 70 percent from April to May. In the West Pool and Lake Gatlin, densities declined during the sample period. For all pools combined, density and average number of species (but not diversity) went up from April to May.

Although complete data are unavailable for the artificial substrate samplers, some observations can be made. The samplers collected large numbers of chironomids, especially those samplers that were suspended in vegetation. Other species were also collected, but not nearly as many as were found with the conventional Ekman dredge. However, the artificial substrate is apparently suitable for bryozoa (moss animalcules), which were not found in grab samples. After a 7-week exposure period, a great deal of algae had grown over the samplers, interfering with removal of the invertebrates. For that reason, the present masonite samplers will be left in the water for only 4 weeks and have been suspended in a more standardized fashion than the first series.

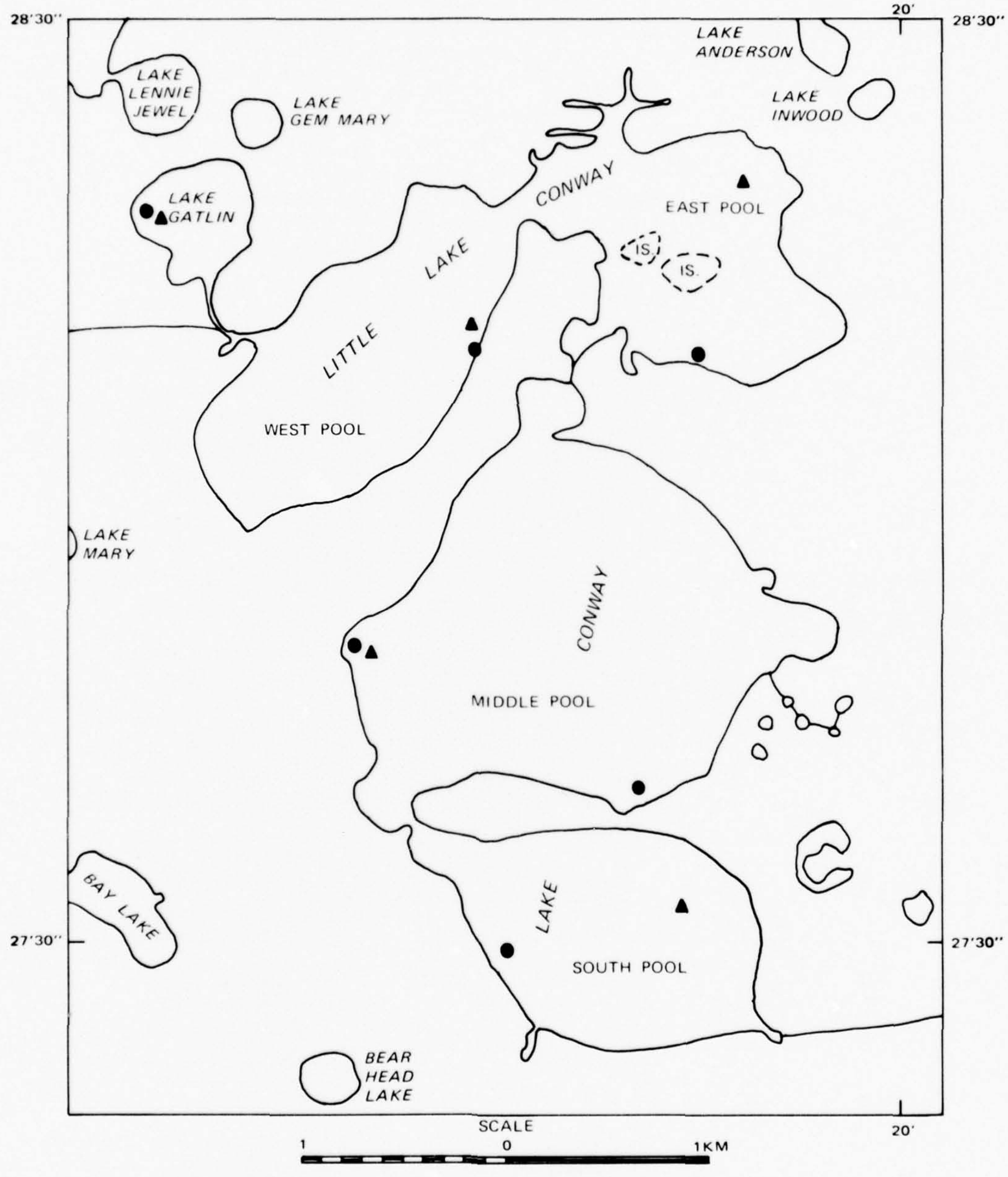

Figure 8. Map of Lake Conway showing location of Hester-Dendy samplers (●) and Periphyton samplers (▲)

Table 5
Benthic Invertebrates Species List for Lake Conway

Division	Subdivision	Species
Turbellaria		*Dugesia tigrina*
Nemertea		Unidentified "A"
Bryozoa		*Plumatella repens* var. *appressa*
Gastropoda	Planorbidae	*Gyraulus* sp.
		Unidentified "A"
	Physidae	*Physa* sp.
	Pilidae	*Pomacea* sp.
	Viviparidae	*Viviparus* sp.
	Pleuroceridae	*Goniobasis* sp.
Pelecypoda	Unionidae	Unidentified "A"
	Sphaeriidae	*Sphaerium* sp.
Oligochaeta	Aeolosomatidae	Unidentified "A"
	Naididae	*Pristina breviseta*
		Dero nivea
	Tubificidae	cf. *Limnodrilus hoffmeisteri*
	Lumbriculidae	*Lumbriculus* sp.
Hirudinea	Glossiphoniidae	*Helobdella* sp.
		Placobdella phalera
Amphipoda		*Hyalella azteca*
Decapoda	Cambarinae	Unidentified "A"
	Palaeomonidae	*Palaeomonetes paludosus*
Hydracarina		Unidentified "A"
Ephemeroptera	Ephemeridae	*Hexagenia* sp.
	Baetidae	*Ephemerella* sp.
Odonata	Zygoptera	*Anomalagrion hastatatum*
		Enallagma sp.
		Unidentified "A"
	Anisoptera	*Epicordulia regina*
		Celithemis fasciata
		Tauriphila australis
Trichoptera	Psychomiidae	Unidentified "A"
	Hydroptilidae	Unidentified "A"
		Hydroptila sp.
	Leptoceridae	*Leptocella* sp.
Lepidoptera		*Nymphula* sp.
Diptera	Culicidae	*Chaoborus albipes*
		Chaoborus albipes pupa
	Ceratopogonidae	*Bezzia setulosa*

(Continued)

Table 5 (Concluded)

Division	Subdivision	Species
Chironomidae	Tanypodinae	*Procladius* sp.
		Tanypus sp.
		Ablabesmyia peleensis
		Clinotanypus sp.
	Chironomini	*Paralauterboniella nigrohalteralis*
		Chironomus attenuatus
		Cryptochironomus fulvus
		Harnischia cf. *viridulus*
		Parachironomus hirtulatus
		Polypedilum halterale
		Endochironomus nigricans
		Glyptotendipes senilis
	Tanytarsini	*Cladotanytarsus* sp.
		Tanytarsus sp.
		Nimbocera sp.
	Orthocladiinae	*Cricotopus* sp.
		Brillia par
		Psectrocladius vernalis
		Chironomidae pupa

Table 6

Comparison of Shallow-Water and Deepwater Stations

Stations	No. of Samples	Average No. of Species	Average No. of Individuals/m^2	Shannon-Weaver Diversity
Shallow	14	13.6	7681	2.53
Deep (4 m)	7	6.3	3970	1.39

Table 7
Some Biological Parameters for Benthic Invertebrate Populations, Grouped According to Sampling Month and Lake Basin

Pool	No. of Samples	Average No. of Species/Sample	Average No. of Individuals/m²	Average Diversity
		April		
South	4	10.0	2,949	2.38
Middle	5	14.8	5,955	2.85
East	4	10.3	4,229	2.60
West	1	12.0	10,701	2.25
Gatlin	1	12.0	8,586	2.83
All	15	11.9	4,919	2.64
		May		
South	5	12.0	4,832	2.58
Middle	6	14.2	10,270	2.35
East	5	14.2	7,379	2.61
West	3	7.7	3,409	1.61
Gatlin	2	7.0	3,409	1.42
All	21	13.0	6,473	2.13
		Both Months Combined		
South	9	11.1	3,948	2.49
Middle	11	14.5	8,327	2.58
East	9	12.5	5,997	2.61
West	4	8.8	5,221	1.77
Gatlin	3	8.7	4,703	1.89
All	36	12.5	5,826	2.34

PERIPHYTON

Methods

The periphyton community is being studied by suspending glass slides in commercially produced samplers (Design Alliance, Inc., Cincinnati, OH). Surface regrowth samplers are set up in each of the five pools (Figure 8). At some stations, samplers have been anchored at 1- or 1.5-m depths as well. Samplers were set out in late June and mid-July, and again in late September and mid-October. Incubation periods varied between 10 and 21 days. Upon retrieval, some of the slides were placed directly in 100 ml of 90 percent acetone and analyzed spectrophotometrically the following day for chlorophyll *a* concentration using the pheophytin correction technique as described by the EPA.[7] The remainder of the slides were placed in wide-mouth bottles containing a 5 percent neutralized formalin solution. Dry and ash-free weights were determined for the preserved samples at 105°C and 500°C, respectively (EPA[7]). Identifications were made using a Unitron inverted microscope, while counts were

performed using Sedgewick-Rafter chambers as described by EPA.[7] For diatom identification, permanent mounts are being made by clearing the organisms with 30 percent hydrogen peroxide and mounting in permount.

The periphyton community is also being assayed as it occurs directly on macrophytic surfaces. At each sampling location, plastic bags are lowered over the top of various macrophytes, below which the plant is clipped and the bag secured. The periphyton assemblage is being studied from the surfaces of *Vallisneria*, *Potamogeton*, *Nitella*, and *Hydrilla*. The surface area is measured for each sample, after which the plant is placed in a Waring blender and homogenized. This detaches the periphyton from the leaf surface, disentangles periphyton clumps, but does not disrupt individual algal cells to any recognizable extent. Identification and counts are made as described above and related to surface area. Biomass to surface area ratios are also being determined. This allows periphyton counts to be related directly to macrophytic biomass.

Results and Discussion

Periphyton dry weights and ash-free weights are presented in Table 8. Since samplers put out in mid-October have not yet been retrieved, many values remain unavailable. There appears to be a large variation between pools, with Lake Gatlin and the South Pool being least productive. In general, much greater productivity is found at depths of 1 and 1.5 m than at the surface. For the values available, productivity seems less during September than in June and July.

Chlorophyll *a* concentrations are presented in Table 9. Again, there appears to be a large degree of variation between pools and depths. Identifications and counts for both regrowth and macrophytic surfaces are presently incomplete.

PHYSICAL-CHEMICAL PARAMETERS

Methods

In conjunction with the biological collections, selected physical-chemical parameters were routinely sampled in Lake Conway. Depth, Secchi disc, dissolved oxygen, temperature, pH, and samples for chlorophyll *a* are routinely taken at all stations. Temperature and oxygen are measured *in situ* at 1-m intervals using an oxygen-thermistor thermometer probe (Yellow Springs Instrument Co.). Additional samples are collected for oxygen analysis by the Winkler method. Field measurements of pH are performed using a portable pH meter (Beckman). Water samples for chlorophyll *a* analysis are stored at 4°C in the dark and returned to the laboratory where extraction and pheophytin corrected chlorophyll determinations are performed using standard methods (EPA[7]).

Results and Discussion

Table 10 presents monthly means for physical-chemical parameters. Surface temperatures in the lakes ranged from 24.1 to 32.5 and showed normal seasonal fluctuations. Significant stratification did exist at the deeper stations in the East and West Pools of Little Lake Conway and Lake Gatlin. By September, this stratification had disappeared, and temperatures were fairly uniform throughout the water columns.

Monthly variations in dissolved oxygen and pH showed no significant trends. However, daily changes for both these parameters did show fluctuations that were consistent with primary productivity in the lake. Hypolimnetic oxygen concentrations reached zero in both pools of Little Lake Conway

Table 8
Periphyton Dry Weight and Ash-Free Weight* (mg/m²/day)

Location	June-July	September-October
Lake Gatlin—Surface	56.9 15.9	NA NA
Lake Gatlin—1.5 m	9.1 7.7	NA NA
West Pool—Surface	8.1 4.9	31.1 31.1
West Pool—1.5 m	749.9 288.2	NA NA
East Pool—Surface	245.8 66.3	102.7 102.7
East Pool—1.5 m	NA NA	148.7 148.7
Middle Pool (West)—Surface	5.5 4.7	9.5 9.0
Middle Pool (West)—1 m	262.5 76.8	21.1 19.4
Middle Pool (East)—Surface	2.8 1.4	NA NA
Middle Pool (East)—1 m	NA NA	NA NA
South Pool—Surface	84.8 19.9	NA NA

* First value given is dry weight.

Table 9
Periphyton Chlorophyll *a* Concentration*
(μg/m²/day)

Location	September-October
Lake Gatlin—Surface	NA
Lake Gatlin—1.5 m	NA
West Pool—Surface	55.2
West Pool—1.5 m	NA
East Pool—Surface	118.6
East Pool—1.5 m	546.6
Middle Pool (West)—Surface	45.2
Middle Pool (West)—1 m	283.4
Middle Pool (East)—Surface	NA
Middle Pool (East)—1 m	NA
South Pool—Surface	64.8

* Values for June-July not available.

Table 10
Monthly Means of Physicochemical Parameters in Lake Conway
April Through August 1976

Date	Temperature °C	Dissolved Oxygen mg/l	pH	Secchi Disc m	Chlorophyll *a* mg/m³
April	25.38	8.83	--	3.08	2.47
May	25.60	8.30	7.38	2.40	3.81
June	27.95	8.90	7.26	2.22	4.32
July	30.70	7.80	7.96	1.85	5.04
August	30.43	7.91	8.06	1.80	--
September	28.08	7.61	7.85	1.98	8.72

during May through August. By September, there were no oxygen deficits in any of the pools, probably a reflection of isothermal conditions present in that month.

Secchi disc transparencies showed a decreasing trend, which correlated with increases in algal abundance throughout the summer. Generally, Secchi disc values were lower at the northern stations.

Chlorophyll increased throughout the summer reflecting the increase in phytoplankton biomass. Variations between pools within any month showed increasing chlorophyll levels from south to north.

CONCLUSIONS

The Lake Conway system is complex with much biotic and abiotic variation between the five pools. With the small amount of data thus far gathered, a firm designation of trophic status for the system is impossible. However, the mean hypolimnetic oxygen concentrations, the Secchi disc values, and the chlorophyll *a* levels point to mesotrophy. Biological parameters indicate trophic status differences within the system, with the East and West Pools and Lake Gatlin on the eutrophic side of mesotrophy and the South and Middle Pools on the oligotrophic side.

Since the process of eutrophication is a very complicated phenomenon involving the interrelationships between physical, chemical, and biological factors, simple descriptive terms, such as eutrophic, mesotrophic, and oligotrophic, do not always adequately describe a lake's trophic condition. To quantify trophic state several numeric indices have been developed. Most notable have been the methods of Shannon and Brezonik[11] and Carlson.[8] Both of these indices increase in value as the trophic state of the lake changes from oligotrophic to eutrophic.

Figure 9 illustrates the relationship between trophic state and chlorophyll. Because of its ease of calculation and simplicity, one of Carlson's trophic state indices was used. It was calculated by the formula:

$$TSI_{(SD)} = 10(6 - \log_2 \text{Secchi Disc Value})$$

The range of Carlson's index is from 0 to 100. The values calculated for the entire Lake Conway system place this group in the middle of the index.

The biota examined thus far also indicate mesotrophy. The large biomass of submersed vascular

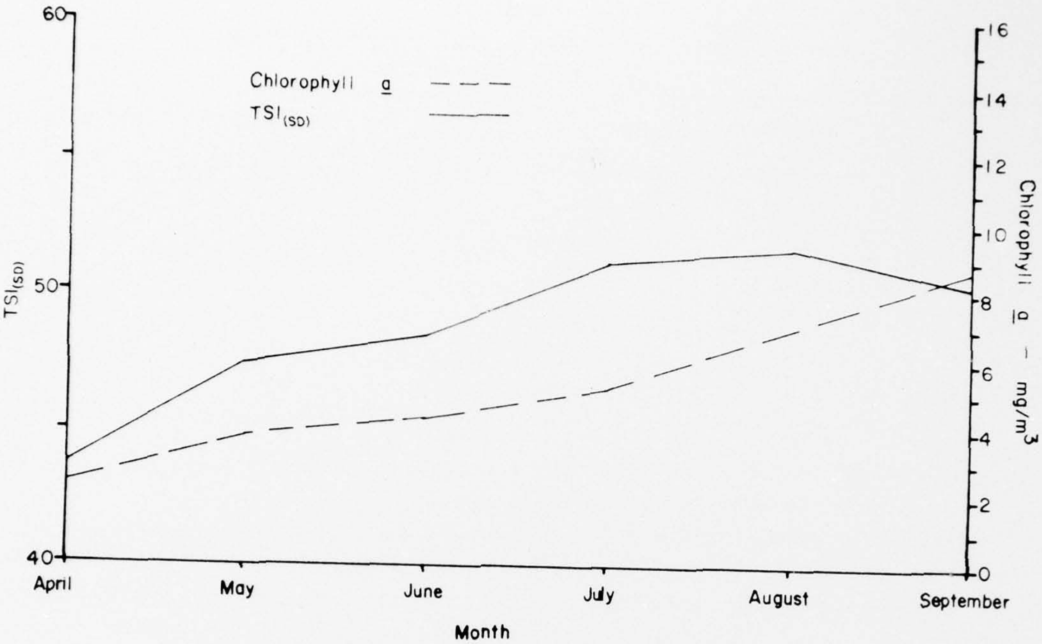

Figure 9. Comparison of Carlson $TSI_{(SD)}$ and chlorophyll *a* (average from all pools)

plants and macroscopic algae, however, may be indicative of excessive nutrient loading. While a preliminary nutrient budget indicates a loading rate characteristic of a mesotrophic lake, further refinement may indicate otherwise.

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BACKGROUND WATER-QUALITY ANALYSIS OF LAKE CONWAY

by

A. T. Sawicki*

ABSTRACT

The Orange County Pollution Control Department has been performing comprehensive water-quality analyses on area lakes since 1972. Beginning with January 1976, the department has analyzed Lake Conway water quality more intensively under contract to the U. S. Army Engineer Waterways Experiment Station (WES). A brief comparison between historical data obtained from 1972 through 1976 with the more recent data indicates water quality in Lake Conway is relatively predictable, varies somewhat from pool to pool, and is subject to short-term seasonal and other variations.

INTRODUCTION

Let me introduce Orange County to you in a brief overview to give you an idea of what our interests are. First of all, Orange County covers about 1000 square miles and has 1100 lakes larger than 5 acres. We are charged with the job of monitoring and preserving water quality throughout the county. Lake Conway, of course, is just one of the urban lakes that we monitor most frequently. There are roughly 500 different stations in the county that are monitored routinely; that is, stations which are sampled either quarterly, semiannually, or annually. The places monitored most frequently are usually in urban areas where water quality is more likely to be adversely affected and is often critically important to the public. Occasionally we monitor lakes in the outlying areas whenever there is a possible change of water quality due to a spill or some other problem.

OPERATING PROCEDURE

What I would like to show you very briefly is the first slide** which I am sure you will recognize. Again you see Lake Conway where, under contract, we sample a total of 11 stations: two in the south portion, three in the Middle Pool, two in the East Pool, three in the West Pool, and one in Lake Gatlin. In addition, five of our own stations are located in the centers of each of these lakes and we have data from them beginning in 1972. These analyses, performed semiannually on surface, middepth, and bottom samples, include 28 chemical parameters, 20 biological parameters, and 5 microbiological parameters listed below in Table 1. Note the parameters which are periodically reported under contract to WES.

Now let me illustrate briefly the way our sampling program is conducted in the field. The Secchi disc and turbidity in Jackson Turbidity Units are used as measures of water clarity. The Kemmerer bottle is used to collect samples at the surface, middepth, and bottom of lakes and streams. In cases where the water depth is less than 6 ft we do bilevel sampling. The standard Winkler method of dissolved oxygen

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** Slides mentioned herein are not depicted in this report.

Table I
Routine Analytical Water-Quality Parameters*

Chemical	Biological	Microbiological
Dissolved Oxygen**	Chlorophyll *a***	Adenosine Tri Phosphate
Biochemical Oxygen Demand**	Chlorophyll *b***	Fecal Indicators, total coliforms
Chemical Oxygen Demand**	Chlorophyll *c***	Fecal Indicators, fecal coliforms
Hardness**	Ratio, Chlorophyll *b:a*	Fecal Indicators, fecal streptococci
pH**	Functional, chlorophyll *a***	Standard Plate Count, aerobes
Alkalinity (as $CaCO_3$)**	Nonfunctional, chlorophyll *a***	
Acidity**	Cartenoids, non-asticians**	
Phosphorous, total**	Pack Cell	
Phosphorous, ortho**	Total Live Algae	
Phosphorous, total unfilterable**	Min. No. Species	
Nitrogen, as NO **	Cyanophyta, coc.	
Nitrogen, as NO **	Cyanophyta, fil.	
Nitrogen, as NH **	Chlorophyta, coc.	
Nitrogen, organic**	Chlorophyta, fil.	
Conductivity**	Chlorophyta, flag.	
Chlorides**	Euglenophyta	
Solids, total**	Chrysophyta, diatoms centrics	
Solids, suspended**	Chrysophyta, diatoms penates	
Solids, volatile**	Chrysophyta, diatoms other	
Secchi Disc Reading**	Other algae	
Turbidity, Jackson Turbidity Units**		
Sodium**		
Calcium**		
Magnesium**		
Potassium**		
Iron**		
Copper**		
Lead**		

* Performed according to Standard Methods, Water and Wastewater, 14th Edition, 1976
** Analyses performed under contract to WES.

analysis is used, although more recently we have been using the Hydro-lab instrument, which electronically measures 6 chemical parameters. These include dissolved oxygen, pH, temperature, depth, oxidation reduction potential, and conductivity.

This slide shows the wet chemistry portion of our laboratory and in the back you see the refrigerator where we receive and store samples. The bottles are brought in the back door at that point and proceed through the lab.

The next slide shows some of our laboratory instrumentation. For example, an automatic diluter; next, to measure pH you see an ion probe; next the Kjeldahl nitrogen test apparatus; and finally an Atomic Absorbtion Analyzer for trace metal analyses.

In our biology laboratory you see a spectrophotometer for measuring some biological parameters. Other instrumentation in this lab includes optical microscopes, centrifuges, a variety of field samplers, etc. This lab also keeps preserved samples of macroinvertebrates that are representative of the biota in lakes and streams at various points in time.

Finally, our department does chemical weed control and we participate in biological control methods as well. There is a wide variety of aquatic weed problems in Lake Conway as you see in this slide where there are submergent as well as emergent weeds. In this slide of a finger canal in Lake Conway, you see a turbidity problem caused by green algae as well as clumps of slime and filamentous algae.

Our department is also concerned with a host of other problems. For instance, a local enterprising developer is pushing soil into the lake and in doing so he creates local turbidity problems as shown in these two slides. Because of potentially serious water-quality degradation posed by pushing dirt and vegetation into the lake, and because he does not have the required county and state permits, we have an enforcement action against him. While this individual was aware of his responsibilities, many people do not realize how detrimental such activities are to water quality. Probably the most important function we have to perform at this time is to educate the public as to what good water-quality practices are. This includes explaining our needs for extensive background data for purposes of detecting adverse trends or to utilize the information in legal actions; the need for permits which encourage and condone environmentally sound development practices while restricting harmful ones; the economic and environmental advantages of biological over chemical control of aquatic weeds; the need to act promptly to halt sources of pollution, etc.

ANALYSIS

A brief analysis was performed to determine whether the water-quality characteristics of Lake Conway since 1972 differ from those obtained for the WES contract in 1976. For this purpose, six chemical and two biological parameters listed in Table 2 were chosen for analysis and were assumed to be representative of water quality.

Data were obtained from the files of the Pollution Control Department (PCD) and from information obtained for WES. Table 3 cross references sampling station identifications which are used later in the report.

The first step in the analysis consisted of computing the mean and standard deviation for each parameter at each station. Each surface, middepth, and bottom sample was treated as valid data point, rather than combining samples to get a representative value for each station. This procedure tends to increase the dispersion or standard deviation because surface and bottom values of certain parameters are consistently different. For example, inspection of raw data indicates the dissolved oxygen of surface samples is usually greater than that of bottom samples.

Table 2
Representative Water-Quality Parameters

Chemical	Biological
Dissolved oxygen (DO)	Chlorophyll *a*
Biochemical oxygen demand (BOD)	Non-astician carotenoids
pH	
Alkalinity (Alk)	
Phosphorous, total (P_t)	
Nitrogen, organic (No)	

Table 3
Sampling Station Identifications

Area Lakes	Midpoint of Lake	WES Station
Lake Conway		
South Pool	BC-9	1
		2
Middle Pool	BC-8	3
		4
		5
East Pool	BC-6	6
		7
West Pool	BC-7	8
		9
		10
Lake Gatlin	BC-11	11

RESULTS

The means and standard deviations for the eight parameters are shown in Figures 1 through 8. Note that the results for the points designated as BC-9, BC-8, BC-6, BC-7, and BC-11 over the 4-year time span from 1972 through 1976 are generally close to those for the first 9 months of 1976 taken at Stations 1 through 11 chosen by WES. However, there are some exceptions for Lake Gatlin (Station BC-11), where the means for BOD, P_t, and No (Figures 2, 5, and 6) and the standard deviations for DO, BOD, Alk, and P_t (Figures 1, 2, 4, and 5) are significantly greater for the 4-year period than for the 9-month period in 1976. This information indicates that water quality in Lake Gatlin varies significantly from time to time and its water quality is somewhat poorer than that in the four lobes in Lake Conway. This is evident by the significantly higher values of BOD, P_t, and No.

Figures 9 through 16 are intended to illustrate seasonal trends in the eight representative parameters and to reveal any anomalies between the 1972-1976 PCD data and the 1976 WES data. Referring to Figures 10, 12, 13, and 14, there appear to be differences in trends between the PCD and WES sets of data for BOD, alkalinity, phosphorus, and nitrogen. It is interesting to note that there are corresponding anomalies in the means between these sets of data in Figures 2, 4, 5, and 6. In fact, the particularly large fluctuations in Lake Gatlin water quality noted earlier may be at least partially responsible for the anomalies. In addition, the 1972-1976 data are somewhat incomplete since analytical results for the months of May, August, and December were entirely lacking, and the number of samples tabulated for a few of the other months were quite small. Perhaps seasonal trends would be more apparent if they were grouped in bimonthly, quarterly, or other groupings.

CONCLUSIONS

The data shown in Figures 1 through 16 are based on about 600 samples, half of which pertain to PCD data for the 1972-1976 time period and the remainder to 1976 samples obtained under the WES

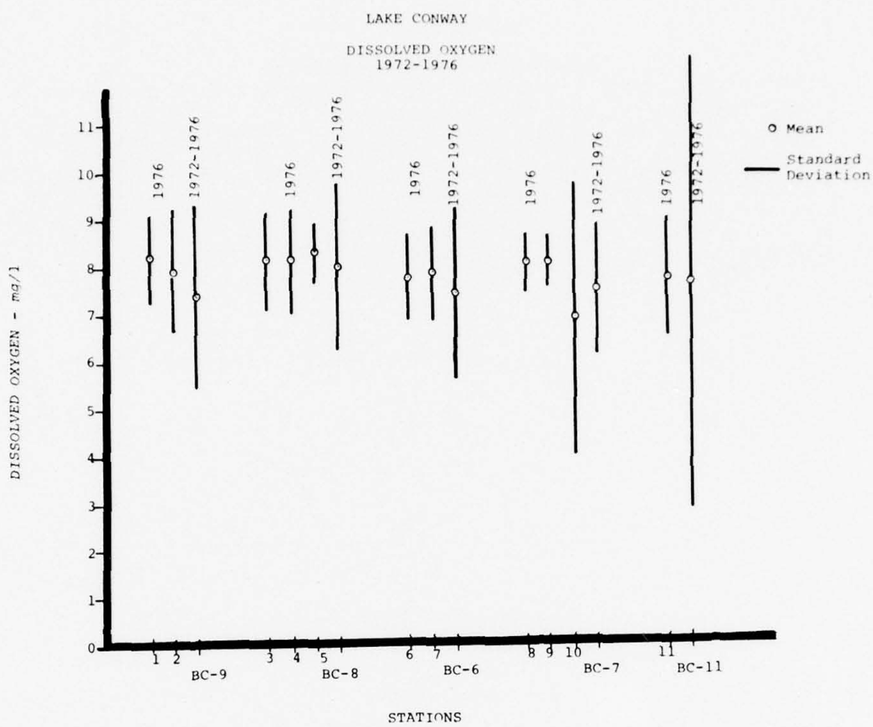

Figure 1. Mean and standard deviations for dissolved oxygen, 1972-1976

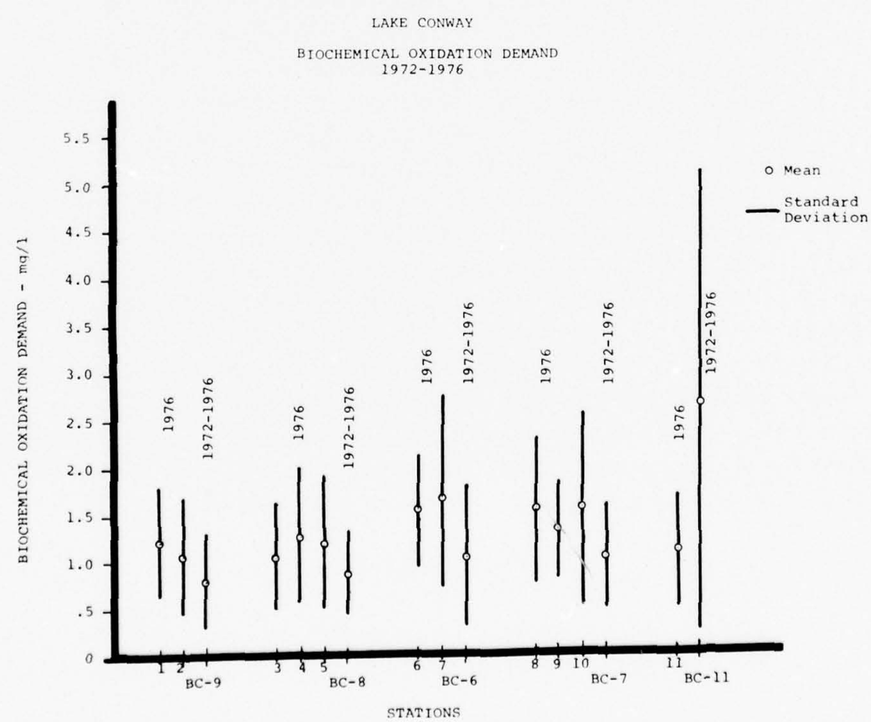

Figure 2. Mean and standard deviations for biochemical oxidation demand, 1972-1976

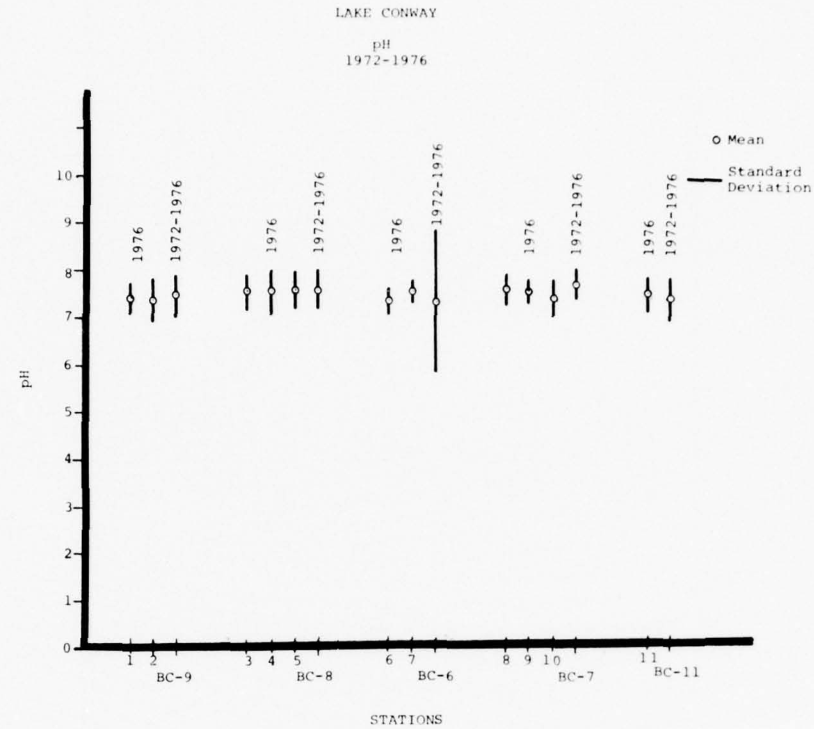

Figure 3. Mean and standard deviations for pH, 1972-1976

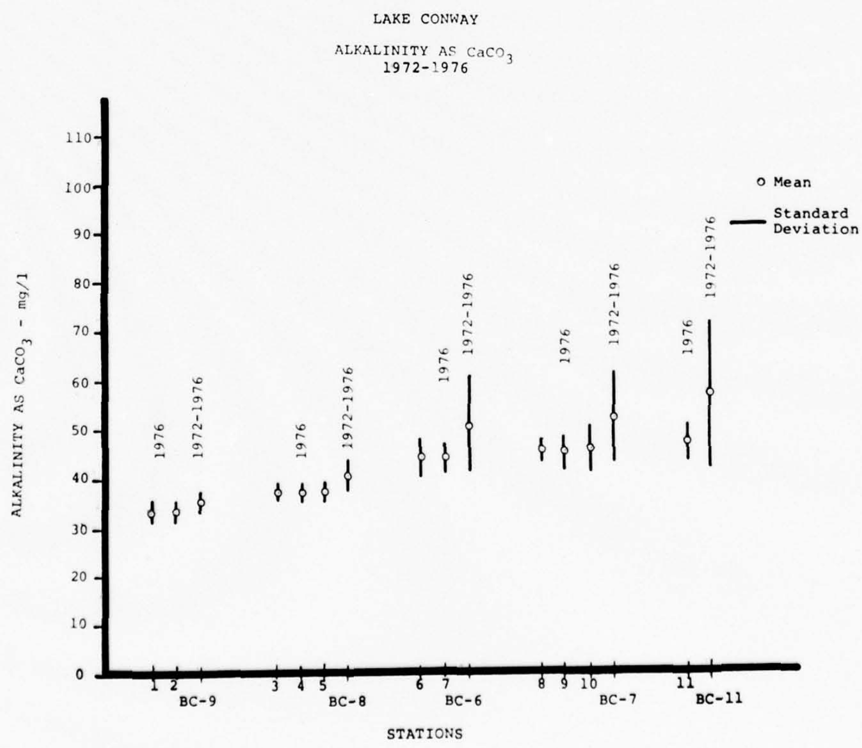

Figure 4. Mean and standard deviations for alkalinity as $CaCO_3$, 1972-1976

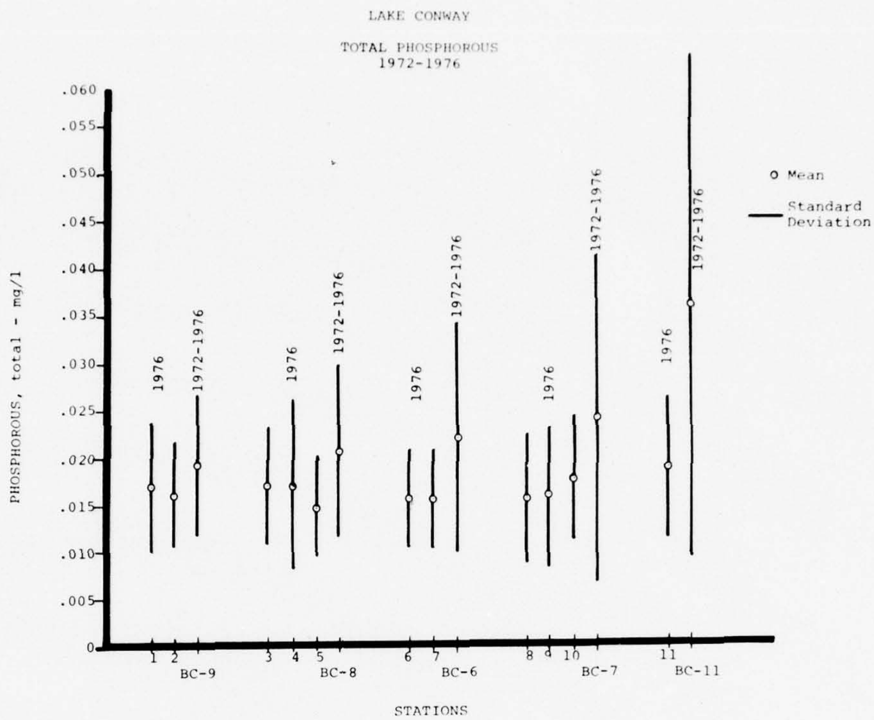

Figure 5. Mean and standard deviations for total phosphorous, 1972-1976

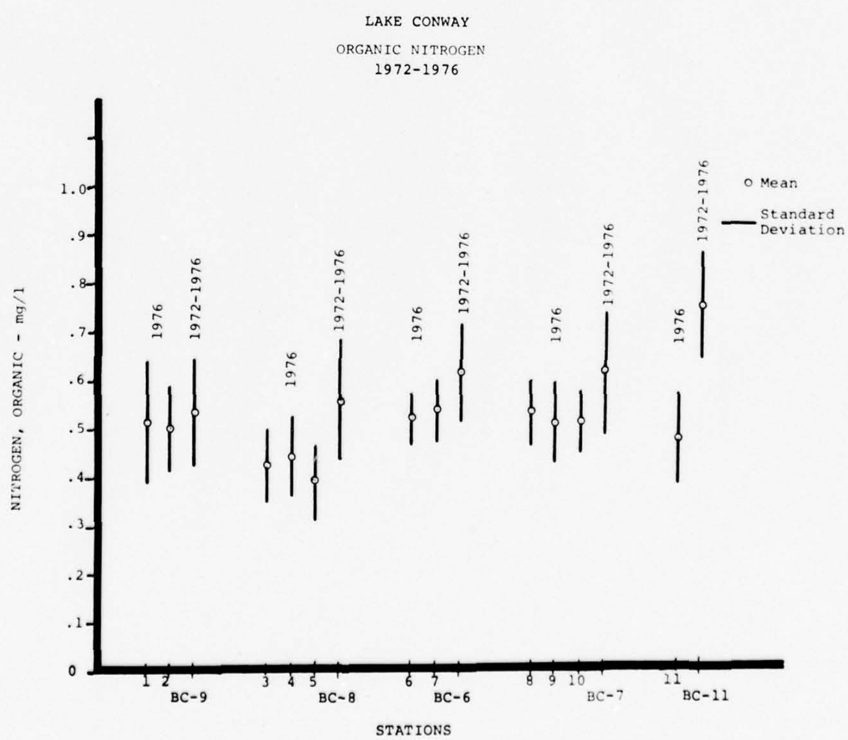

Figure 6. Mean and standard deviations for organic nitrogen, 1972-1976

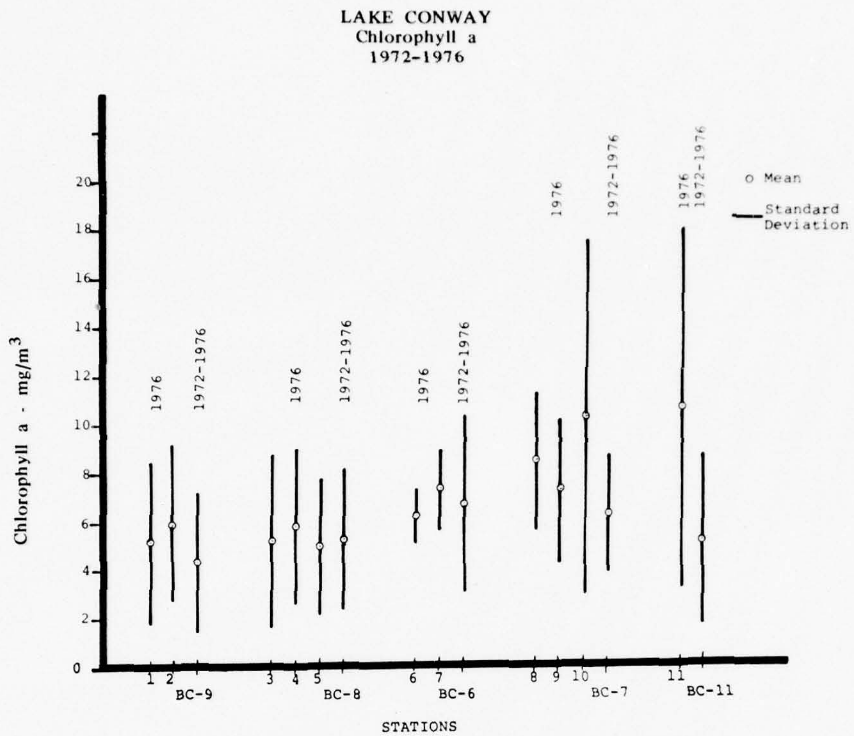

Figure 7. Mean and standard deviations for chlorophyll *a*, 1972-1976

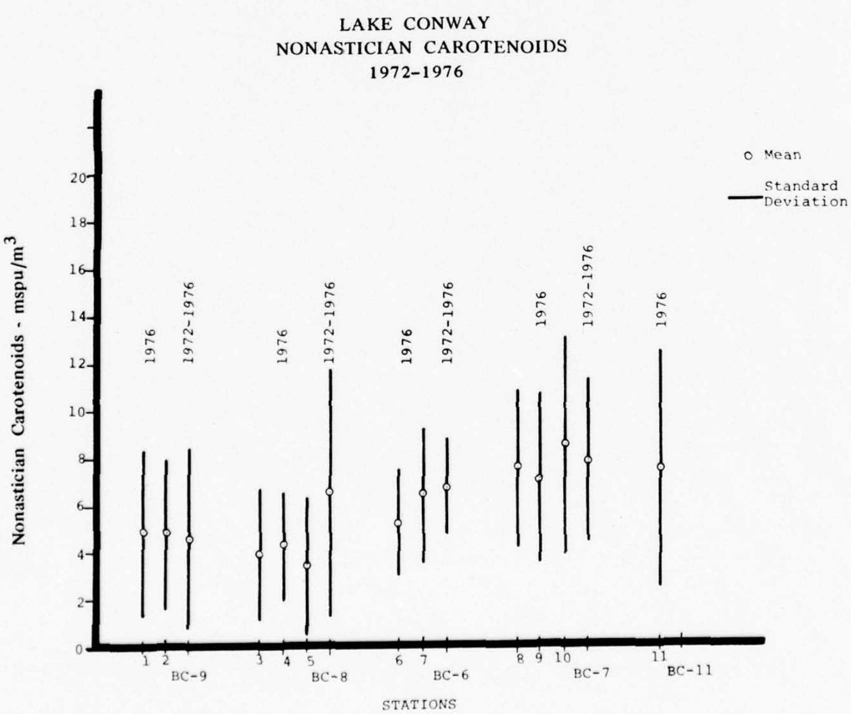

Figure 8. Mean and standard deviations for nonastician carotenoids, 1972-1976

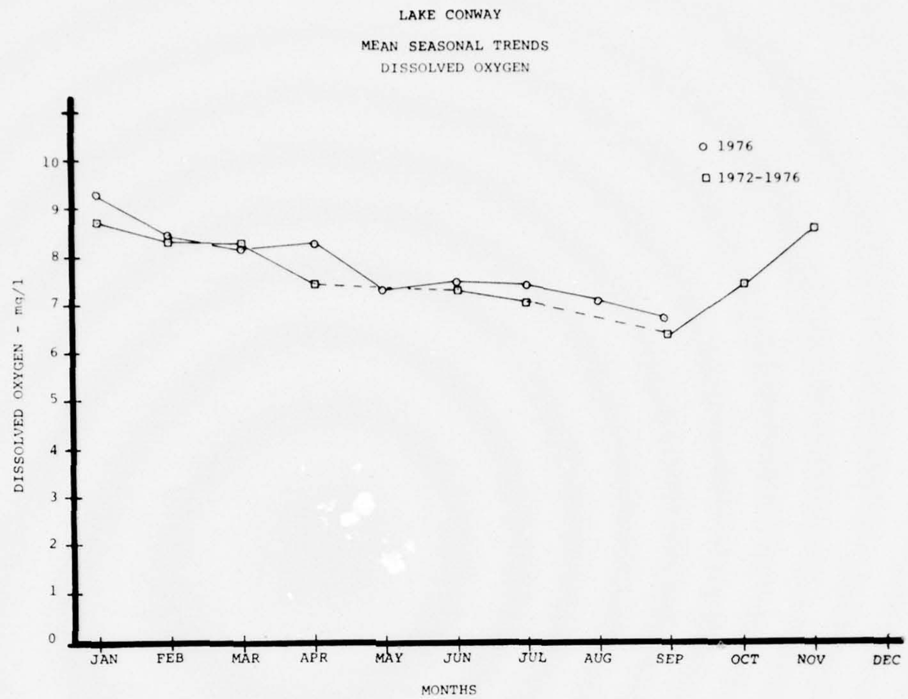

Figure 9. Mean seasonal trends for dissolved oxygen, 1972-1976

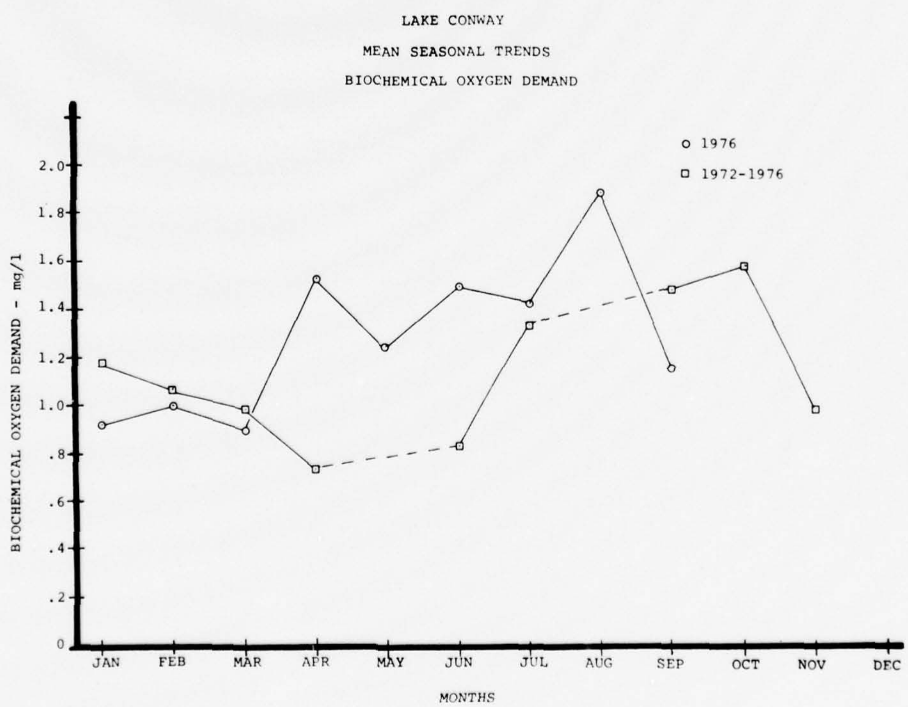

Figure 10. Mean seasonal trends for biochemical oxygen demand, 1972-1976

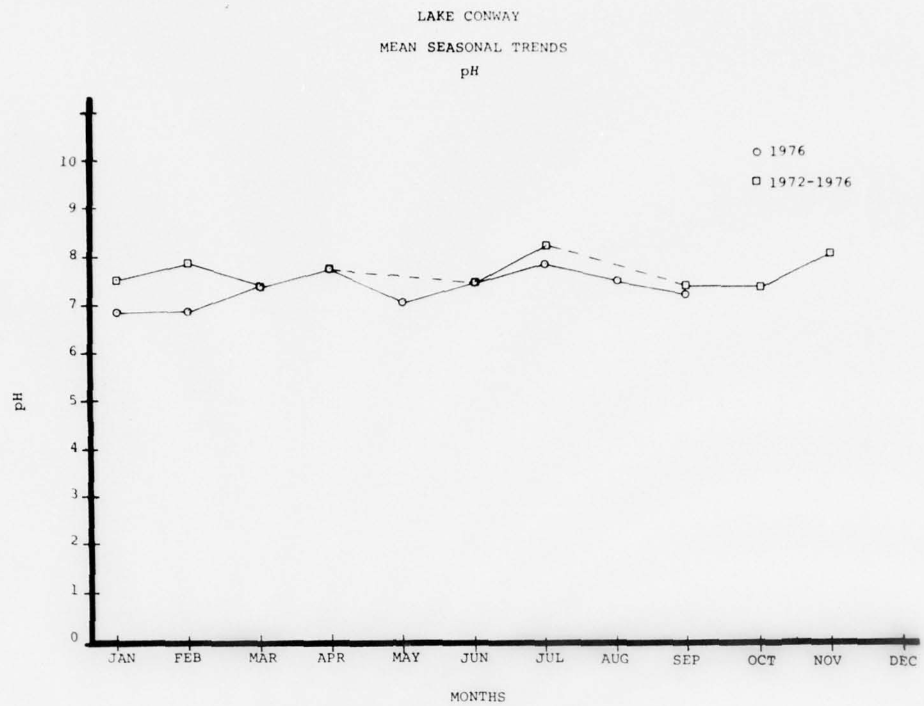

Figure 11. Mean seasonal trends for pH, 1972-1976

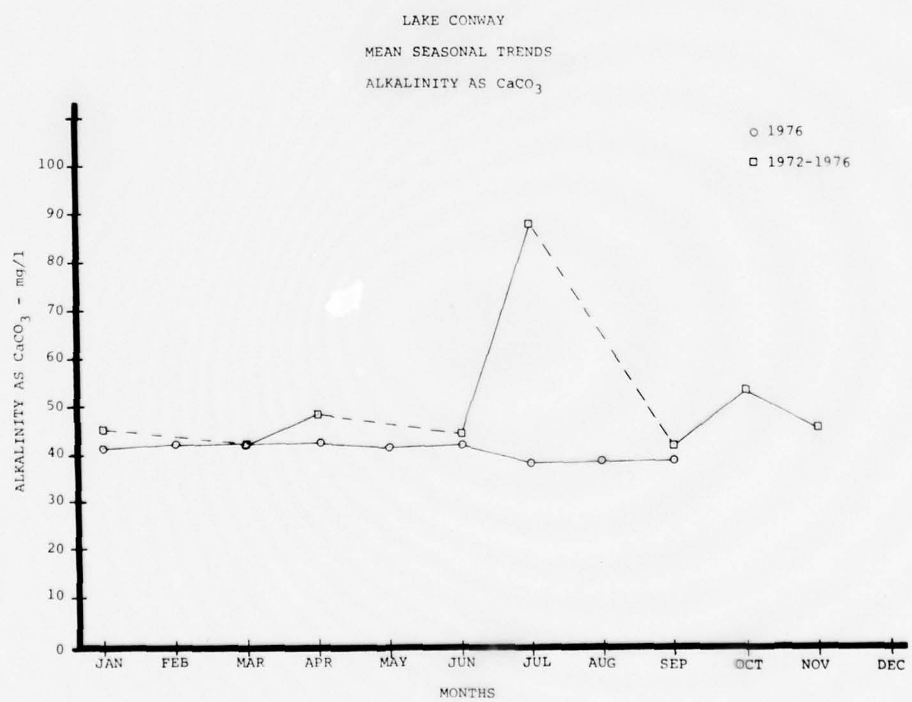

Figure 12. Mean seasonal trends for alkalinity as $CaCO_3$, 1972-1976

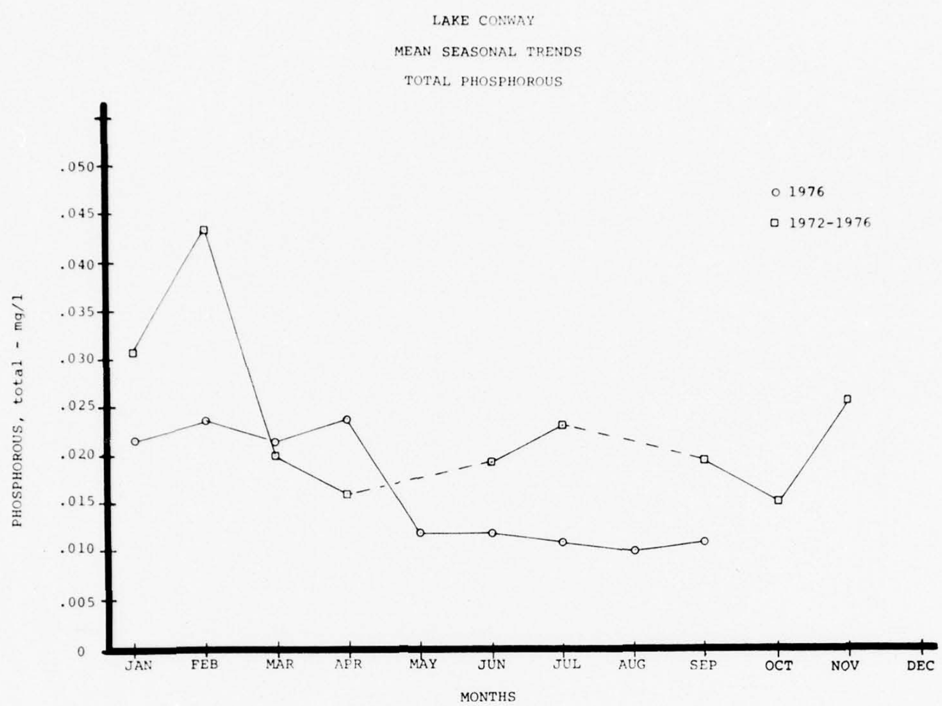

Figure 13. Mean seasonal trends for total phosphorous, 1972-1976

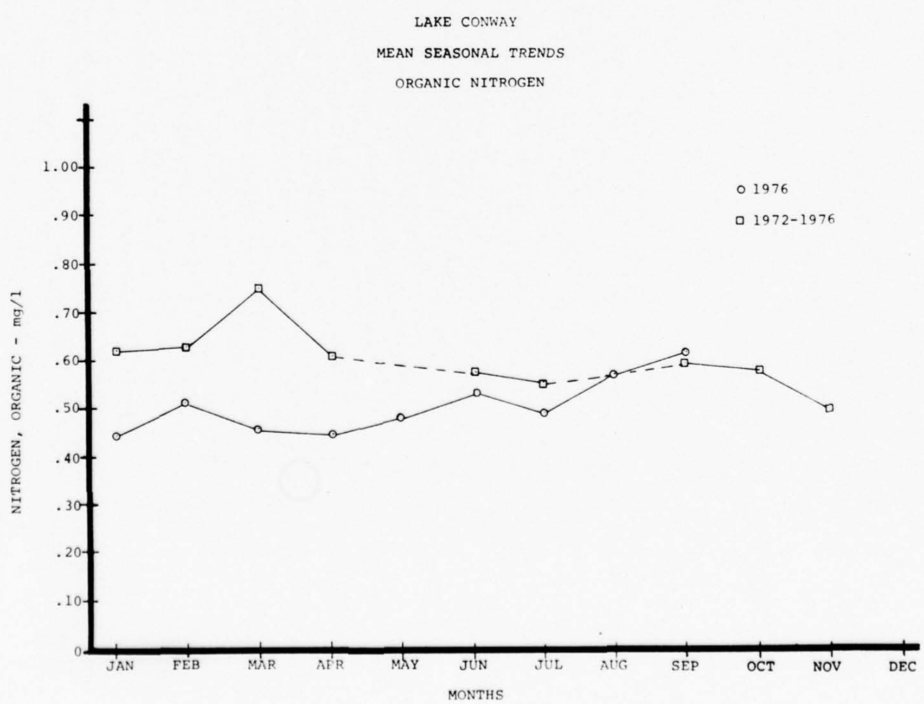

Figure 14. Mean seasonal trends for organic nitrogen, 1972-1976

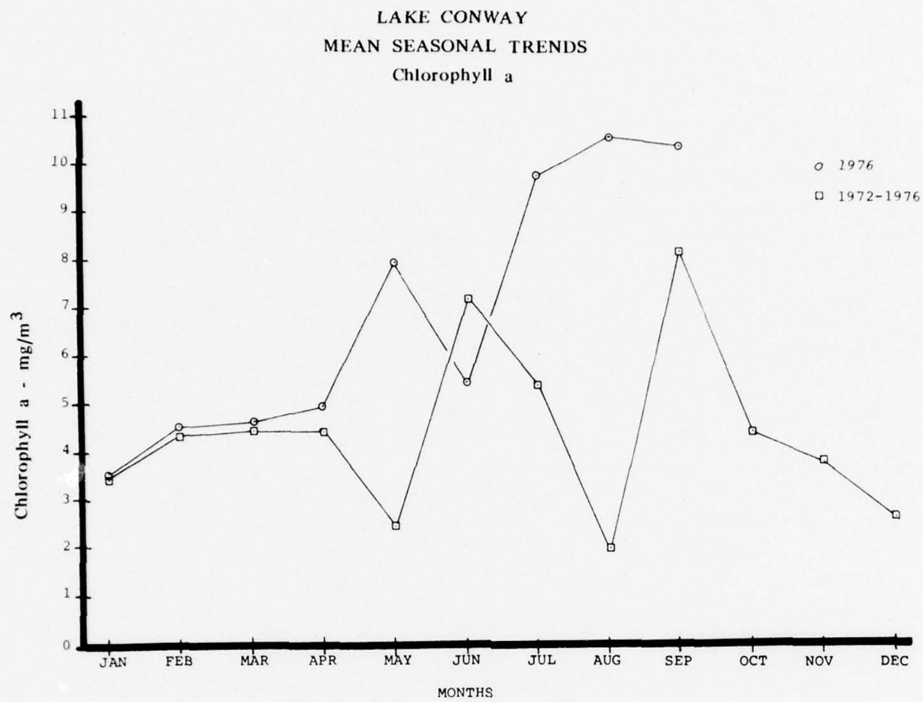

Figure 15. Mean seasonal trends for chlorophyll *a*, 1972-1976

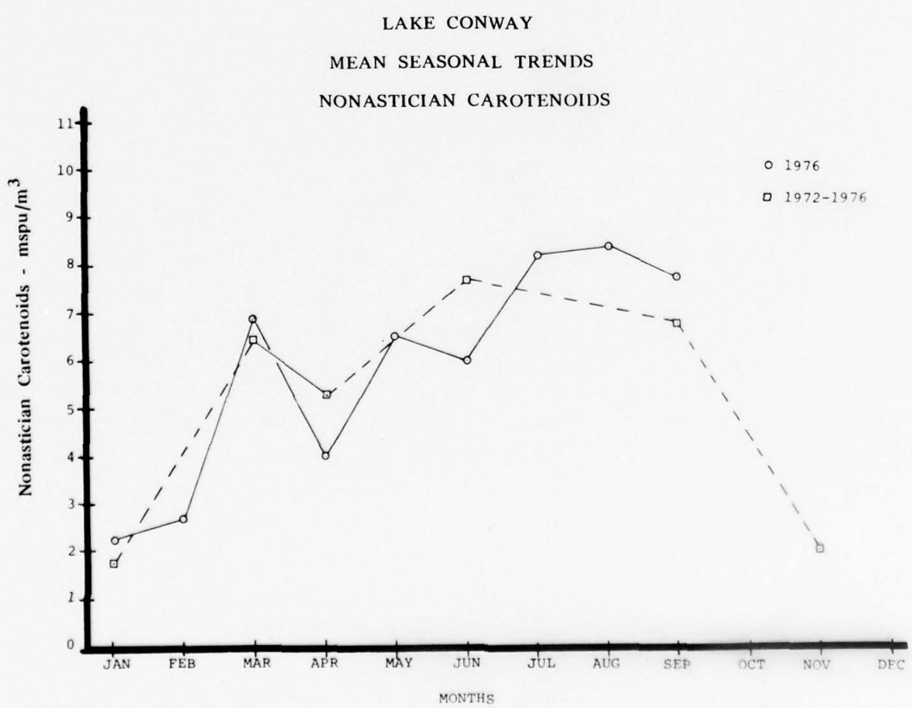

Figure 16. Mean seasonal trends for nonastician carotenoids, 1972-1976

contract. While this number of samples seems large enough to support certain statistical inferences of water quality regarding the long-term and seasonal conditions of Lake Conway and Lake Gatlin, the following conclusions should be considered.

a. Two parameters that have small variations in their means and standard deviations are pH and alkalinity (Figures 3 and 4). Also, they do not appear to have significant seasonal variations (Figures 11 and 12).

b. Over the 1972-1976 time period, water quality in Lake Gatlin (Stations 11 and BC-11) varied widely as shown by the large standard deviations in Figures 1, 2, 3, and 7. On the other hand, for reasons that are not apparent at this time, water quality in Lake Gatlin in 1976 appears very similar to that of Lake Conway (Stations 1 through 10 and BC-6, BC-7, and BC-9).

c. Seasonal trends between PCD (1972-1976) and WES (1976) data appear to be closely correlated for dissolved oxygen and nonastician carotenoids (Figures 9 and 16). However, there seems to be an inverse seasonal relationship between these two parameters, that is, DO is high when carotenoids are low, and conversely.

d. Correlations of seasonal trends between PCD and WES data are not readily apparent from Figures 10, 13, 14, and 15 for BOD, P , No, and Chlorophyll *a*. While such correlations are expected, they may be lacking owing to shortcomings in data. For example, the dashed lines in the figures indicate that no PCD data were obtained for the intervening months. Thus, peaks in parameters which were measured or which may have been missed very likely biased the trend lines and obscured the expected correlations.

e. The PCD and WES data in Figures 1 through 8 exhibit significant overlapping in the standard deviations of the eight selected parameters. These data strongly suggest water quality in Lake Conway has been relatively stable since 1972. However, Figures 9 through 16 also indicate that seasonal changes in water quality do occur, and analyses for one particular season are not necessarily representative for other seasons. Therefore, improperly designed experiments may bias results if such seasonal variations are not properly analyzed.

PROPOSED RELATIONSHIPS BETWEEN WHITE AMUR AND THE AQUATIC ECOSYSTEM AT LAKE CONWAY, FLORIDA

by

K. C. Ewel* and T. D. Fontaine III**

INTRODUCTION

The U. S. Army Corps of Engineers is currently conducting a large-scale field test of the ability of the white amur (*Ctenopharyngodon idella* Val.) to control excessive growths of hydrilla (*Hydrilla verticillata* Royle) in a Florida lake ecosystem. The test is being carried out at Lake Conway in Orange County, Florida. Lake Conway is 7.6 km^2 and over 8 m deep at its deepest point. The lake is surrounded by residential developments, although small sections of its shoreline remain relatively undisturbed.

In order to predict the long-term effects of the use of white amur, a model of the ecosystem at Lake Conway is being formulated, which will provide a basis for interpreting the effect of the fish not only on the population of hydrilla but on the entire ecosystem as well.

The purpose of modelling usually includes more than prediction, however. The process of constructing a model often points out additional data needs, and simulations may disclose relationships between components of a system that were not obvious before. For these reasons, it is useful to begin modelling efforts at the beginning of a project, if not before. The model presented here for Lake Conway was assembled before fieldwork began, so it contains only a small amount of data that had been gathered on the lake itself. It therefore represents a concept of a lake ecosystem in the southeastern United States, based primarily on published results from temperate lake ecosystems.

ASSUMPTIONS OF MODEL

The model currently being simulated is shown in Figure 1. The computer program used to simulate the model is listed in the Appendix. The emphasis at this stage of the modelling process is on interactions between a key nutrient, phosphorus, and the four main categories of plants: phytoplankton, periphyton, hydrilla, and native submersed macrophytes. The data used to calculate the values of pathways and amounts of each of the state variables were taken from the literature and from the small amount of information previously collected on the lake itself. The model, therefore, represents a generalized model for a Florida lake, but does not yet specifically represent Lake Conway.

Forcing Functions

Solar energy, temperature, and rainfall and runoff with their associated inputs of phosphorus are the external controlling factors that are considered to be most important to the functioning of the lake ecosystem.

Solar radiation. Monthly solar radiation values are graphed in Figure 2. Full solar radiation is

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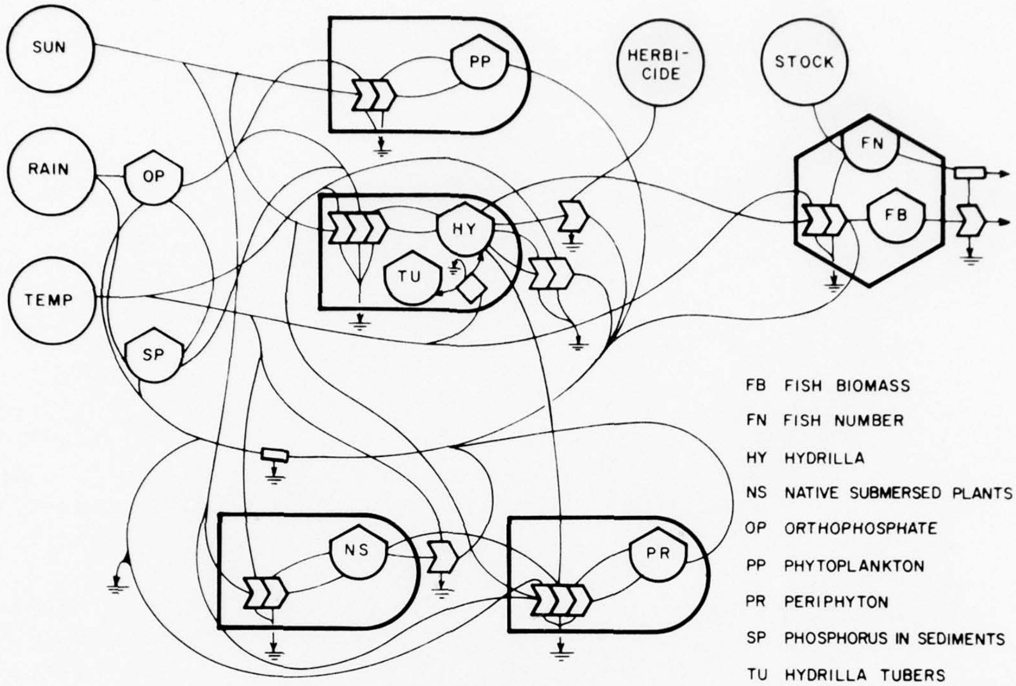

Figure 1. Model of Lake Conway ecosystem currently being simulated

assumed to reach the vascular plants whose leaves are near the surface of the water, as well as the phytoplankton and the periphyton. New growth of hydrilla, however, is dependent on sunlight filtering through several metres of water. A special term (START) has, therefore, been included to take into account not only the extinction coefficient of water but the shading effect of phytoplankton and other vascular plants as well.

Temperature. Surface water temperatures from Lake Conway are also shown in Figure 2. Temperature plays an important role in controlling the rates of photosynthesis and respiration in aquatic organisms. The relationship between net photosynthesis and temperature in three species of aquatic vascular plants is presented in Table 1. Data summarized in Sculthorpe[3] suggest that respiration rates increase 1.32 to 3.48 times for each 10° C rise in temperature in many aquatic macrophytes. A value of 1.4 was arbitrarily selected for all the plant species used in this model. In order to combine temperature relationships for net productivity and respiration into a factor that could be used to express temperature dependence of gross primary productivity, the values for net primary productivity and respiration were converted to a relative scale in which the highest value for the three reference temperatures became one, and the other two values were a fraction of that. The relative values for net productivity and respiration were then summed (Table 2), and the resulting value for gross primary productivity was in turn converted to a relative scale. These factors, when included in the productivity term, provide a temperature dependence that makes gross primary productivity in vascular plants sensitive to the changes in temperature between 10 and 30°C. In this model, respiration, but not photosynthesis of periphyton and phytoplankton, was considered to be temperature-dependent.

Phosphorus. Two fractions of phosphorus are distinguished in this model: orthophosphate, or that

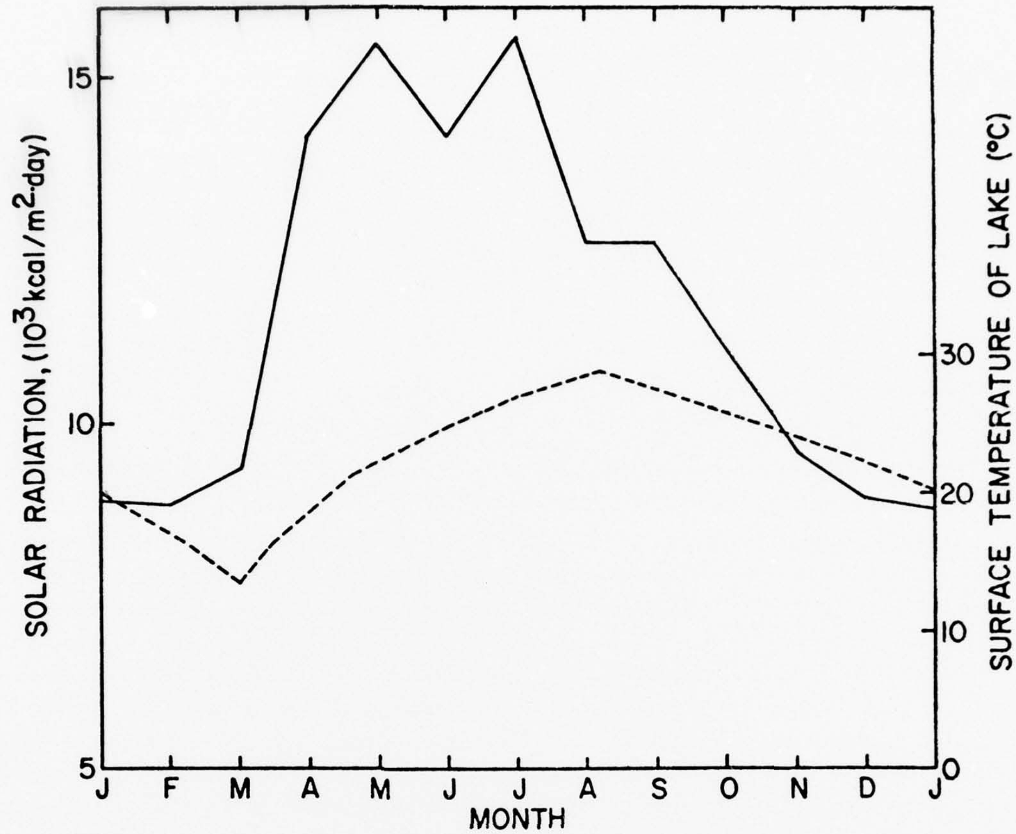

Figure 2. Solar radiation input[1] and average surface water temperature (Orange County Pollution Control, personal communication) for Lake Conway, Florida

Table 1
Net Photosynthesis of Three Aquatic Plants*

Temperature °C	Hydrilla	Net Photosynthesis Potamogeton	Vallisneria
10	19.8	7.3	5.3
20	31.6	9.0	4.6
30	18.3	5.9	4.0

* μ moles 0_2/g. fr. wt.-hr (Garrard[2]).

Table 2
Relative Productivity and Respiration Rates for Hydrilla and Native Submersed Plants

	Hydrilla			Native Submersed Plants		
Temperature	**NPP***	**R****	**GPP†**	**NPP††**	**R**	**GPP**
10	0.63	0.55	0.67	0.93	0.55	0.85
20	1.00	0.74	1.00	1.00	0.74	1.00
30	0.58	1.00	0.91	0.75	1.00	1.00

* Relative value for net primary productivity, calculated from values in Table 1; all values were divided by the largest.
** Respiration function: $0.63 \times e^{.03(\mathrm{Temp})}$; all values divided by largest.
† Relative value for gross primary productivity, calculated by summing the values for NPP and R , then dividing by the largest value.
†† Relative net primary productivity values for native submersed plants were calculated by averaging the values in Table 1 for *Potamogeton* and *Vallisneria* and dividing by the largest.

fraction which is dissolved in water and readily available for plant uptake; and particulate phosphorus, that portion which is tied up in organic matter in the plants and sediments. Phosphorus exists in other forms, but these appear to be the most important and are assumed to constitute the entire pool of total phosphorus.

Monthly inputs of total phosphorus and orthophosphate via rainfall and runoff are listed in Table 3. In this model, orthophosphate entering the lake is available to plants for uptake. The particulate phosphorus, however, sinks to the sediments, where it must be remineralized before becoming available to the plant population again. Remineralization appears to occur fairly rapidly under anaerobic conditions. However, the orthophosphate that is formed cannot reenter the lake water as long as the top few centimeters of the sediments are oxidized, since orthophosphate under these conditions is bound to clays and iron compounds and is retained in the sediments. When the bottom layers of water contain less than 1 mg/l of oxygen, however, the orthophosphate is released into the water.[9]

Dissolved oxygen levels in Lake Conway are low enough from April to October to permit release of orthophosphate, since warmer temperatures during these months bring about increased rates of respiration in benthic organisms. The rate of flow of orthophosphate from lake sediments into the lake water was estimated to be 1 g/m^2, a value reported for undisturbed sediments.[10]

Plant Populations

The plant populations in the lake have been grouped into four categories: phytoplankton, periphyton, hydrilla, and native submersed macrophytes. These four categories differ in their responses to sunlight, temperature, and nutrient concentrations, as well as to interspecies interactions (Figures 3 and 4).

Hydrilla. Hydrilla invests a considerable proportion of its productivity in the fall into tubers that sprout the following spring. Since hydrilla tends to grow in deeper waters, new growth might be more dependent on energy stores in these tubers than on sunlight. As the growing plant nears the surface of the water, with its roots in the sediments below, it branches laterally, forming a mat that quickly shades out plant life below and exhausts the carbon dioxide supply in the surface waters, limiting photosynthesis.[11]

Table 3
Rainfall and Runoff Inputs to Lake Conway, with Associated Phosphorus Inputs

Month	Rainfall* m	Runoff** m	Total Phosphorus† mg/m^2	Orthophosphate†† mg/m^2
January	0.12	0.24	54.8	47.4
February	0.07	0.14	31.1	26.9
March	0.11	0.21	47.3	40.8
April	0.07	0.14	32.2	27.8
May	0.12	0.24	54.1	46.7
June	0.17	0.33	75.6	65.3
July	0.16	0.31	71.1	61.4
August	0.18	0.37	83.5	72.2
September	0.29	0.58	131.2	113.4
October	0.03	0.06	12.6	10.9
November	0.02	0.04	8.4	7.3
December	0.07	0.13	29.2	25.3

* Climatological data.[3]
** The drainage basin was estimated to be 32.9 km^2;[4] and it was estimated that 50 percent of the rainfall in the area becomes runoff.
† Average total phosphorus concentration in rainfall was 0.056 mg/l at Lake Okeechobee,[5] and is estimated to be 0.2 mg/l in runoff from an urban watershed.[6]
†† Orthophosphate has been found to be 82 percent of total phosphorus in rainfall in Florida,[7] and 87 percent in runoff from an urban watershed.[8]

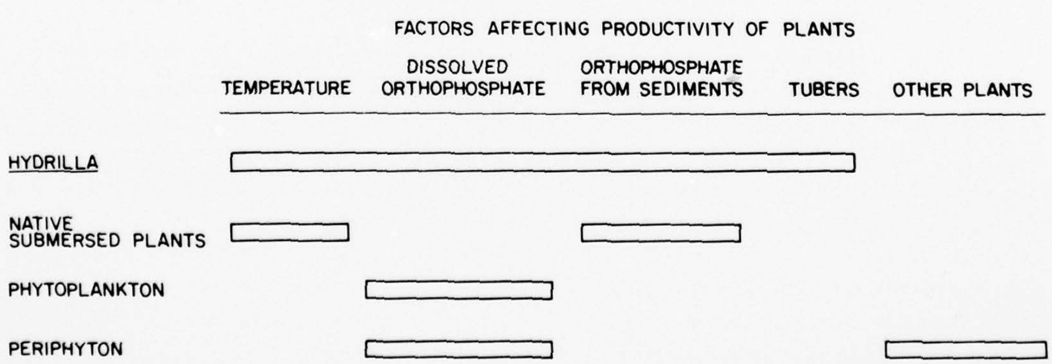

Figure 3. Factors affecting productivity of plant populations in ecosystem model (Figure 1)

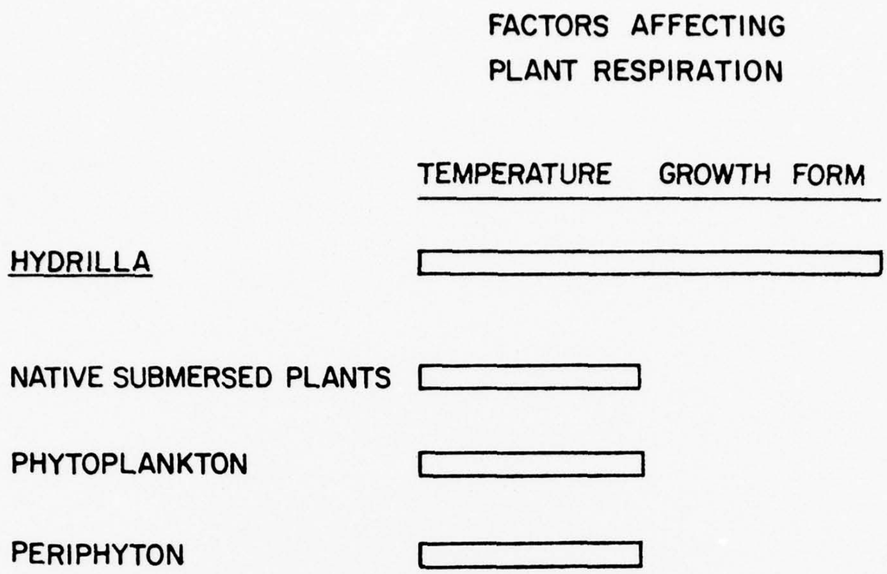

Figure 4. Factors affecting respiration of plant populations in ecosystem model (Figure 1)

In this model, the net effect of this growth habit is to increase the rate of respiration. The temperature sensitivity of photosynthesis and respiration in hydrilla has already been discussed.

Little is known about the rate of uptake of nutrients in aquatic plants. It is assumed here that the process is driven by photosynthesis and that the turnover time for phosphorus in the plants is the same as for carbon. The site of uptake is a matter under considerable debate. One study[12] suggested an unusually high dependence by hydrilla on its root system, in spite of a very low root-shoot ratio. Lomolino (unpubl. ms.) found that hydrilla is capable of taking up phosphorus through both roots and leaves. It was assumed for this model that 60 percent of the uptake is through the leaves, and 40 percent through the roots. Nutrient output, or leaching, is assumed to be equal to the rate of respiration. However, the catabolic pathways of respiration and death are not differentiated in this model. Forty percent of the phosphorus taken up by the plant is, therefore, assumed to be carried to the sediments, and 60 percent is released to the water as orthophosphate.

Productivity of hydrilla was estimated to be 6 g-C/m^2-day, the upper end of a range of productivity values for aquatic plants.[13] Simulation of the model started in July, when it was assumed that productivity is maximum. Initial hydrilla biomass was estimated to be 32.5 g-C/m^2 (roughly 5 tons wet weight per acre).

Native submersed plants. The native submersed plants, primarily *Nitella*, *Potamogeton*, and *Vallisneria*, are also affected by temperature, although there is less variability in its effect on photosynthesis than there is for hydrilla. No surface mat is formed by these species, and growth is primarily around the shallow fringes of the lake (*Nitella* is actually found in deeper water).

In this model, it is assumed that the macrophytes use only nutrients in the sediments. Some species of aquatic plants appear to depend entirely on roots for their nutrient supply, including an African species of *Potamogeton*.[12]

Gross primary productivity of this group of plants in July was set at 4 g-C/m^2-day. Initial biomass level was 8 g-C/m^2.

Phytoplankton. The assumption is made in this model that phytoplankton productivity is much more dependent on solar radiation than on temperature. Phytoplankton obtain all their nutrients from orthophosphate dissolved in the water; 90 percent of this is returned to the water as orthophosphate, and 10 percent sinks to the sediment. The temperature-dependence factor for phytoplankton respiration is: $0.3 \times e^{.04(\mathrm{Temp})}$.[14]

Gross primary productivity of phytoplankton was set at 1 g-C/m^2-day, and initial biomass at 1 g-C/m^2.

Periphyton. Periphyton differ from phytoplankton in being attached to the leaves of macrophytic plants. Therefore, they are dependent not only on solar radiation but on availability of appropriate substrate as well. The primary difference between periphyton and phytoplankton in this model is that periphyton are assumed to derive the orthophosphate they need from the leachate of the plants on which they are situated. Only half of the phosphorus in periphyton is returned to the water as orthophosphate; the other half sinks to the sediments.

Control Mechanisms

Herbicide. The level at which hydrilla is considered to be a nuisance was arbitrarily determined to be 32 g-C/m^2. When this level is reached in the model, plant biomass is reduced by as much as 90 percent.

White amur. A model representing the important features of a population of nonbreeding white amur is shown in Figure 5. In this model, it is assumed that the fish do not reproduce and that they eat only hydrilla. Therefore, the number of fish in a lake at any given time depends on their initial stocking rate and their death rate. Death rate is a linear function, removing about 14 percent of the existing number each year.

The rate at which biomass is converted from plant to flesh was determined from data available in the literature. The regression shown in Figure 6 relates increase in biomass of individual fish to rate of plant consumption.[15,16] There appears to be no difference between consumption rates of the three plant types tested, but there were significant differences between the amounts of weight gained from the different plant types consumed (Figure 7). Fish gained much more weight from eating *Hydrilla* and *Najas* up to the point where 0.8 to 1 kg per fish was being consumed each day, after which more weight was gained from *Ceratophyllum*. The equation for fish production contains these regression equations as well as a temperature-dependence factor. The rate of consumption was arbitrarily estimated to increase 2.0 times for every 10°C rise in temperature across the range of temperatures represented in this model.

Also included in this model was the addition of white amur fecal material to the ecosystem; a high percentage of the material consumed by the fish was estimated to pass through without being assimilated. It was assumed that 60 percent of the phosphate in the feces leaches directly into the water as orthophosphate, and 40 percent sinks to the sediments as particulate phosphorus.

SIMULATION OF MODEL

Effect of Controls

Simulations of the undisturbed growth pattern of hydrilla and the effect of control by herbicide, white amur, and combined herbicide and white amur are shown in Figure 8. Little seasonal variation in hydrilla occurs when growth is undisturbed. In reality, however, a mat of hydrilla slowly sinks to the

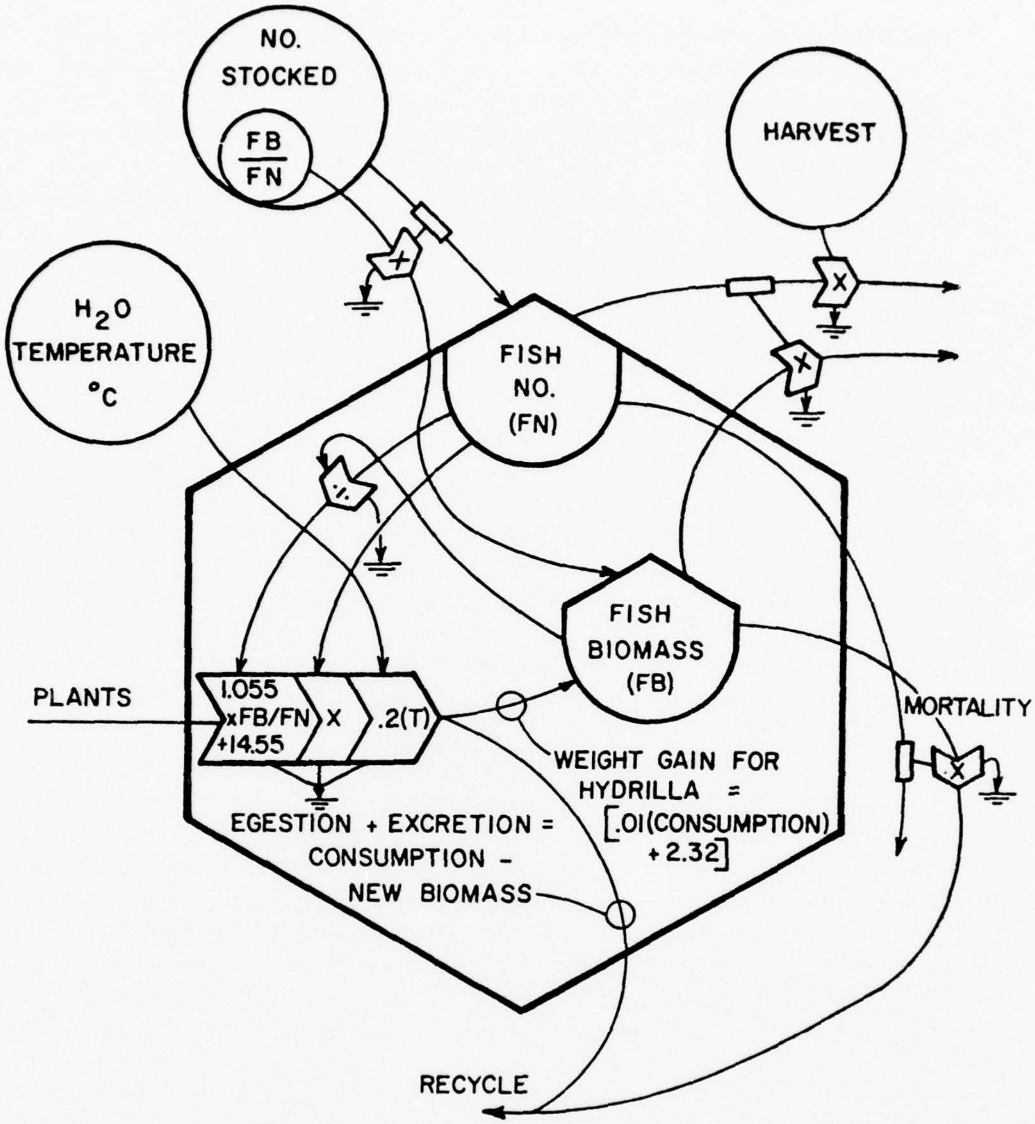

Figure 5. Model of nonreproducing white amur population which feeds solely on hydrilla

bottom of the lake in the fall, and the subsequent year's growth sprouts from this mat.*

Application of herbicide is extremely effective in reducing biomass, but regrowth is rapid, usually occurring within a year. However, when white amur are stocked at a rate of 30 per acre and about 1 kg per fish, it takes slightly less than 7 years for the hydrilla biomass to be reduced to less than 10 percent of its original level. When white amur and herbicide are used together, the same level of control is achieved in less than 2 years.

A variety of stocking rates was simulated in which fish ranging in size from 250 to 2000 g were added

* W. H. Haller, personal communication.

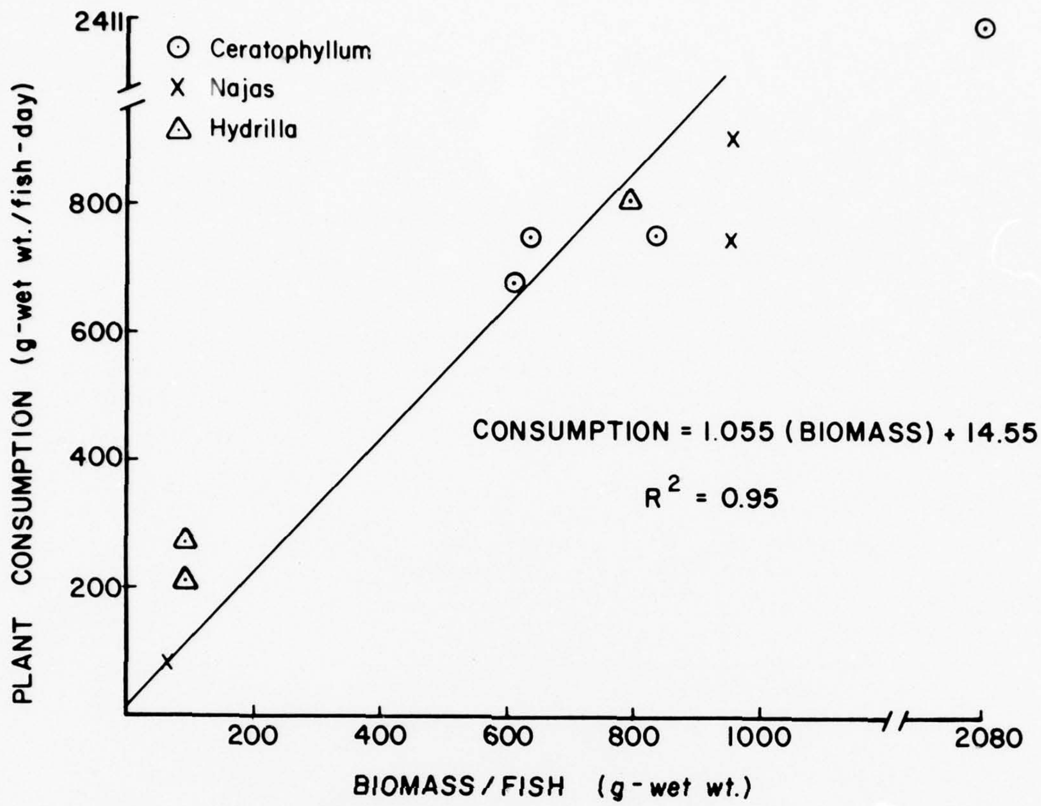

Figure 6. Relationship between rate of consumption and size of white amur when fed on three species of aquatic plants

at densities ranging from 5 to 40/acre. In general, greater biomass led to faster control time, with a range of approximately 2 years (Figure 9). Most rapid control was obtained by stocking 1500-g fish at 30/acre; biomass in this case was reduced to 10 percent of its original level in 6 years.

The pattern of control is similar in all cases. Gross primary productivity of hydrilla is higher the second summer than the first, and it increases in subsequent summers in those cases where stocking is lower. The effect of the fish is not manifested before the third summer in any of the cases simulated. As fish biomass increases, however, so does grazing pressure. At the same time, orthophosphate levels eventually become high enough (in part because of release of the nutrients from white amur feces) to cause a bloom in the phytoplankton population (Figure 10). This persistent bloom ties up enough of the orthophosphate to affect gross primary productivity in hydrilla, and simultaneous increases in grazing pressure finally cause the hydrilla population to decline considerably—at the fifth summer in the fastest case. Hydrilla recovers somewhat the following spring only to be decimated the next summer. Once biomass has been reduced enough, a combination of the reduced light availability and the continued grazing pressure of the white amur keep the hydrilla at very low levels.

Release of Phosphorus into Lake

The rate at which dissolved nutrients are made available to the plant community is crucial, but few measurements have been performed on the rate at which nutrients are taken up or leached by aquatic plants. Therefore, it has been assumed that uptake by aquatic plants is proportional to photosynthesis,

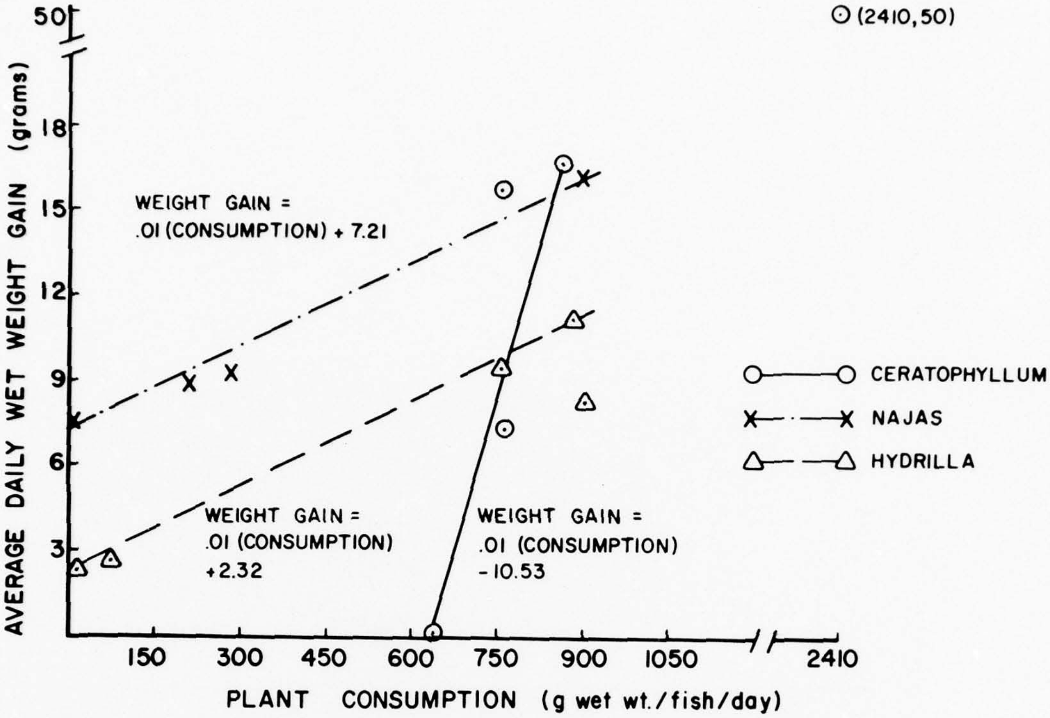

Figure 7. Relationship between weight gained by white amur and rate of plant consumption when feeding on three species of aquatic plants

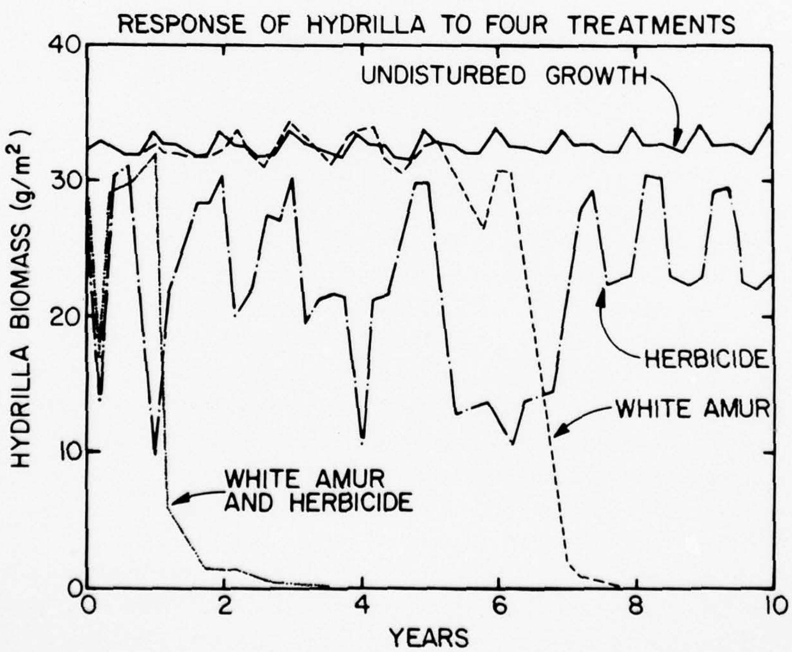

Figure 8. Simulations of model outlined in Figure 1 showing biomass of hydrilla when undisturbed, and when controlled with herbicides, white amur, and a combination of herbicides and white amur

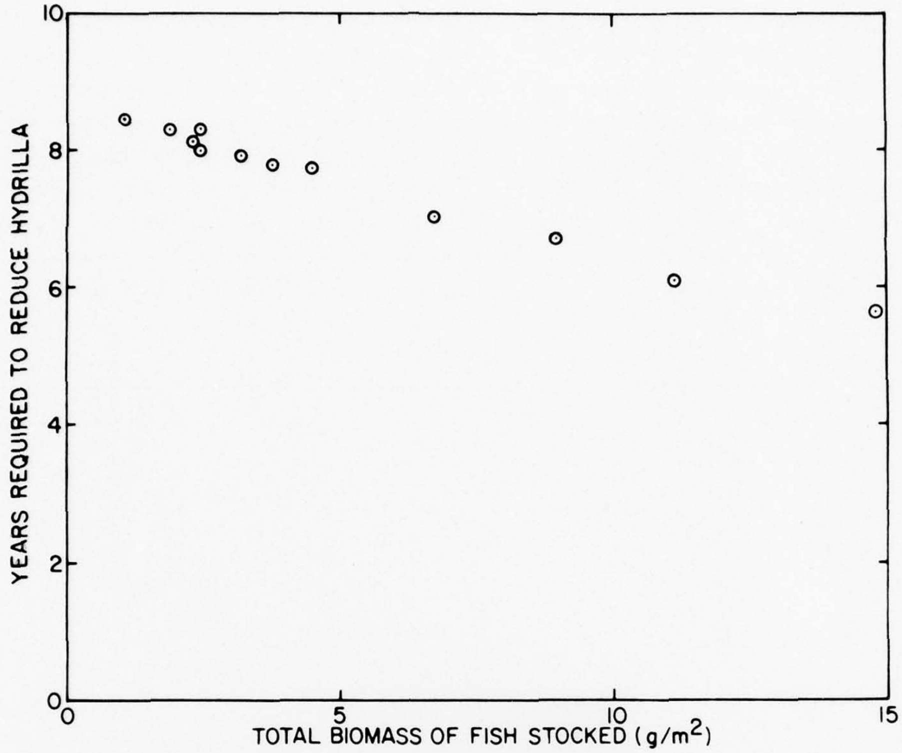

Figure 9. Time predicted by model for white amur at different stocking levels to reduce hydrilla to 90 percent of its original biomass

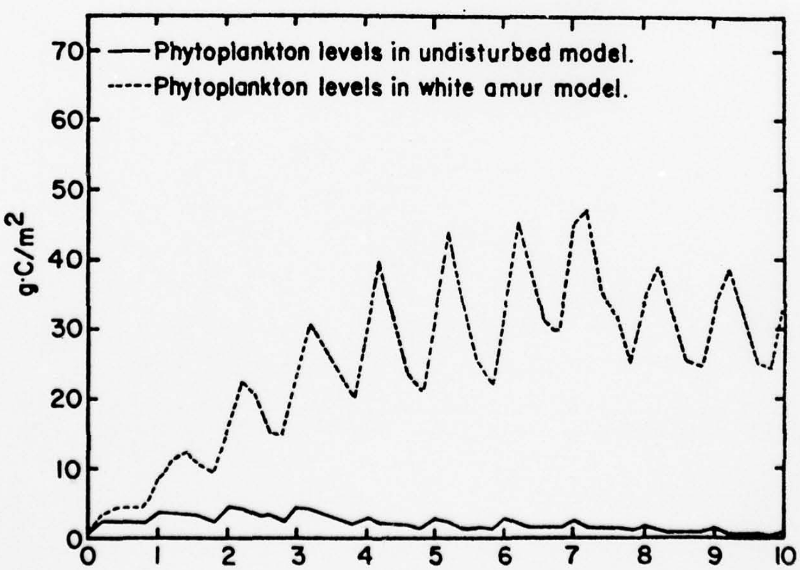

Figure 10. Simulated changes in phytoplankton when hydrilla component is undisturbed and when white amur is included as a control

the proportionality constant determined by the concentration of phosphorus in the plant, and that the output is proportional to respiration. Figure 11 shows the relative magnitude of the different forms of orthophosphate input to the lake. Hydrilla, the dominant macrophyte, provides the greatest input, and each of the plant groups provides more than is made available by remineralization or rainfall and runoff. Since periphyton, phytoplankton, and hydrilla derive at least some of their orthophosphate from the water, the net release from these categories would actually be considerably less than is shown.

The orthophosphate output from the feces of the white amur was monitored during the sixth year after introduction in the control model. Fish biomass was at its peak during this period. The amount of orthophosphate leached from the feces during this period (Figure 12) is roughly equivalent to the amount released from the native submersed plants in the model simulating undisturbed growth of hydrilla.

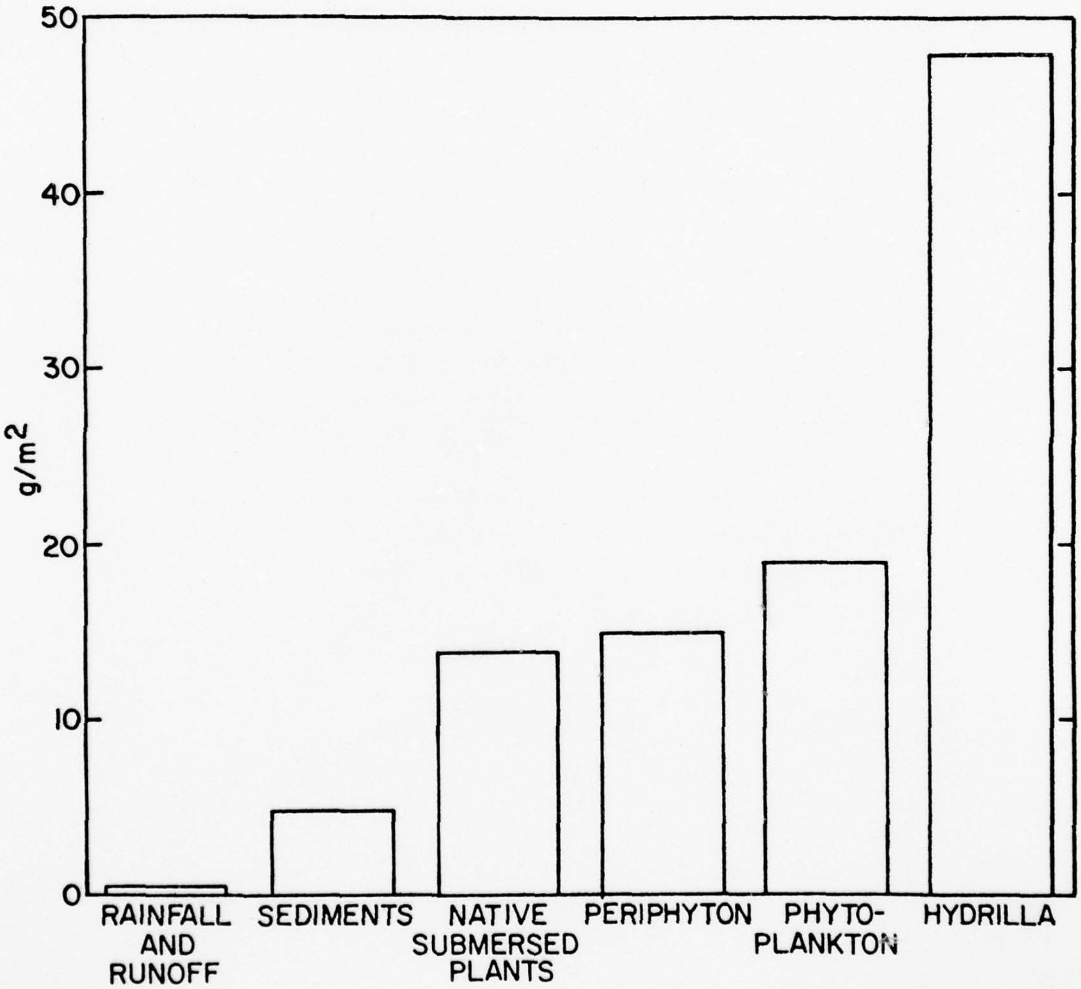

Figure 11. Simulated levels of orthophosphate released annually in lake model from five sources

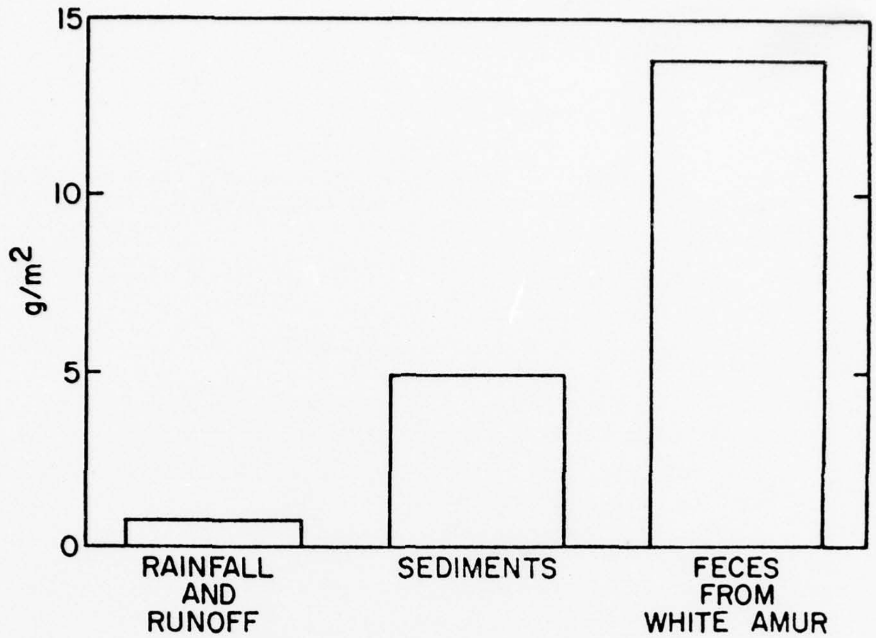

Figure 12. Simulated levels of orthophosphate contributed by white amur in feces, by rainfall and runoff, and by remineralization

RESULTS OF MODEL

The model at this stage of its development has served three important purposes: It has predicted the number of years that might pass before the white amur shows control over hydrilla; it has indicated ways in which we might expect the ecosystem to react to introduction of the white amur; and it has pointed out some serious data gaps in the literature on aquatic plants.

When white amur are used as the principal means of control of hydrilla, their effect may not be visible for 6 years. When they are used in conjunction with herbicides, control appears to be achieved much more rapidly. The density of hydrilla used in this model is fairly low; lakes with higher plant densities might require more time before control is achieved.

If native submersed plants derive all their nutrient needs from the sediments, as this model assumes, then they are little affected by changes in the hydrilla population or dissolved orthophosphate levels. At Lake Conway, native submersed plants predominate in the shallow areas, hydrilla in deeper areas.

The native submersed plants seem to act as a nutrient pump, obtaining nutrients from the sediments and leaching them into the water. Hydrilla probably behaves this way also, although it is not dependent solely on this nutrient source. Changes in nutrient concentrations in the water affect phytoplankton because of their rapid turnover time, so any release of nutrients, whether from hydrilla or from the white amur, will necessarily result in at least a temporary algal bloom.

Considerable data are still needed to define the place and magnitude of importance of aquatic vegetation in nutrient cycling. Important assumptions in this model include the role of aquatic plants as nutrient pumps and the significant effect they have on introduction of orthophosphate into the water. Changes in these assumptions might have considerable effect on the prediction of the impact of white amur on ecosystem dynamics.

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APPENDIX A

PROGRAM LISTING FOR MODEL SIMUL WHITE AMUR AND HERBICIDE O

```
****CONTINUOUS SYSTEM MODE

*** VERSION 1.3 *

TITLE PHOSPHORUS
INITIAL
*INITIAL CONDITIONS
INCON ICTU=10.
INCON ICNS=8.
INCON ICHY=32.5
INCON ICPR=8.14
INCON ICSP=100.
INCON ICOP=.05
INCON ICPP=1.
* INITIALIZATIONS
      START=SUN
CONST TUGROW=117000.
CONST XTNC=.1045
CONST TWILT=124285.
      MAT=1.
      ZERO=0.
      SUN=156706
      TUBON=0.
      TUGERM=1.
PARAM MAY=9.5
CONST CPP=2.86E-2
*RATE CONSTANTS
CONST KHY1=1.49E-3
CONST KHY2=2.5
CONST KHY5=3.
CONST KTU1=.511
CONST KTU2=2.62
CONST KTU3=.125
CONST KNS1=1.17E-4
CONST KNS2=11.15
CONST KPR1=5.02E-6
CONST KPR2=1.34E-5
CONST KPR3=6.5
CONST KPP1=4.66E-3
CONST KPP2=35.5
CONST KOP1=4.46E-2
      ONE=1.
      FWASTE=0.
      I=0.
      NUSINS=32.

*CONSTANTS ASSOCIATED WITH WHITE AMUR
CONST KW2C=.036
CONST KBIS=0.0
CONST KEN1=0.14
CONST KEN2=0.0
CONST KEB2=1.055
CONST KEB3=14.55
CONST KEB4=0.01
CONST KEB5=.77
CONST KEB6=2.32
PARAM STOCK=0.0
INCON ICEN=.0074
INCON ICEB=6.47
```

```
* FORCING FUNCTIONS

* TIME IS DIVIDED INTO TENTHS OF A YEAR, OR DECA-YEARS
FUNCT DCY=0.0,0.,0.1,1.,0.2,2.,0.3,3.,0.4,4.,...
          0.5,5.,0.6,6.,0.7,7.,0.8,8.,0.9,9.,...
          1.0,0.,1.1,1.,1.2,2.,1.3,3.,1.4,4.,...
          1.5,5.,1.6,6.,1.7,7.,1.8,8.,1.9,9.,...
          2.0,0.,2.1,1.,2.2,2.,2.3,3.,2.4,4.,...
          2.5,5.,2.6,6.,2.7,7.,2.8,8.,2.9,9.,...
          3.0,0.,3.1,1.,3.2,2.,3.3,3.,3.4,4.,...
          3.5,5.,3.6,6.,3.7,7.,3.8,8.,3.9,9.,...
          4.0,0.,4.1,1.,4.2,2.,4.3,3.,4.4,4.,...
          4.5,5.,4.6,6.,4.7,7.,4.8,8.,4.9,9.,...
          5.0,0.,5.1,1.,5.2,2.,5.3,3.,5.4,4.,...
          5.5,5.,5.6,6.,5.7,7.,5.8,8.,5.9,9.,...
          6.0,0.,6.1,1.,6.2,2.,6.3,3.,6.4,4.,...
          6.5,5.,6.6,6.,6.7,7.,6.8,8.,6.9,9.,...
          7.0,0.,7.1,1.,7.2,2.,7.3,3.,7.4,4.,...
          7.5,5.,7.6,6.,7.7,7.,7.8,8.,7.9,9.,...
          8.0,0.,8.1,1.,8.2,2.,8.3,3.,8.4,4.,...
          8.5,5.,8.6,6.,8.7,7.,8.8,8.,8.9,9.,...
          9.0,0.,9.1,1.,9.2,2.,9.3,3.,9.4,4.,...
          9.5,5.,9.6,6.,9.7,7.,9.8,8.,9.9,9.,10.,0.
* INCOMING RADIATION
FUNC RAD=0.,156706,.83,126418,1.67,126418,2.5,110616,3.33,96130,...
         4.17,80566,5.,85220,5.83,93697,6.67,140906,7.5,155369,...
         8.33,152755,9.17,140908,10.,156706
FUNCT DECP=0.,27.1,1.,28.7,2.,26.8,3.,24.8,4.,22.5,5.,20.,6.,16.3,...
         6.7,13.5,7.,16.,8.,21.3,9.,24.5,10.,27.1
      FUNCT MATERM=0.,1.,30.,1.,45.,10.
FUNCT RLHY=10.,.67,20.,1.,30.,.81
FUNC RLPS=10.,.85,20.,1.,30.,1.

* ORTHOPHOSPHATE INPUTS -- RAINFALL, RUNOFF
FUNCT ORTHO=0.,6.14,.83,7.22,1.67,11.34,2.5,1.09,3.33,.73,4.17,2.53,...
          5.,4.74,5.83,3.69,6.67,4.08,7.5,2.79,8.33,4.67,9.17,6.53,...
          10.,6.14

* PARTICULATE PHOSPHORUS -- RUNOFF
FUNCT PARTC=0.,1.37,.83,1.13,1.67,1.78,2.5,.17,3.33,.11,4.17,.39,...
          5.,.74,5.83,.42,6.67,.65,7.5,.44,8.33,.76,9.17,1.03,...
          10.,1.37

* PHOSPHORUS RELEASED WHEN WATER IS ANAEROBIC ABOVE SEDIMENTS
FUNCT SEDPH=0.,1.,2.,1.,3.,.5,1.,6.,7.,9.,8.,.5,9.,1.


DYNAMIC

* FUNCTIONS CONTROLLING HYDRILLA
HY=INTGRL(ICHY,HYGROS-TUGRHY*TUMAL*Y-HYRESP+TUGERM*AFTUPATU...
                -HDMAPAH-HYDRAFCNSHD)
      HYGROS=KHY1*START*ALPAHY*PSHY/(1+KHY1*ALPAHY)
      HYRESP=KHY2*HY*PO10*AT
      HDRDSM=PEDRAZ*HY*AHY*A2
      HERB=COMPAR(HY,HUSTAC)

* FUNCTIONS CONTROLLING HYDRILLA TUBERS
TU=INTGRL(ICTU,TUGROW-TUGERM*TUMAL*Y-TUGERM*AFTUPATU-KTU*TU)
      TUGERM=COMPAR(TEMP,22.)
      T1=COMPAR(TIMEY,3.6)
      T2=COMPAR(MAY,TIMEY)
      TUMAL=AND(T1,T2)

* FUNCTIONS CONTROLLING PERIPHYTON
PR=INTGRL(ICPR,PRGROS-PRRESP)
      PRGROS=PRGLY*PRGPHY
      PRRESP=KPR3*PR*PO10
      PRGPHY=KPR2*START*HYLEC*PR/(1+KPR2*HYLECH*PR)
```

```
        HYLECH=.6*ACPR*HYRESP
        PRHYLP=CPR*PRGRHY
        PRHYOP=HYLECH-PRHYLP
        PRGRNS=KPR1*SUN*NSLECH*PRR/(1+KPR1*NSLECH*PRR)
        NSLECH=.6*ACPR*NSRESP
        PRNSLP=CPR*PRGRNS
        PRNSOP=NSLECH-PRNSLP

* FUNCTIONS CONTROLLING PHYTOPLANKTON
PP=INTGRL(ICPP,PPGROS-PPRESP)
        PPGROS=KPP1*SUN*PP*ALP/(1+KPP1*PP*ALP)
        PPRESP=KPP2*PP*PPQ10
        PPQ10=.5*EXP(.08*TEMP)

* FUNCTIONS CONTROLLING NATIVE SUBMERSED PLANTS
NS=INTGRL(ICNS,NSGROS-NSRESP)
        NSRESP=KNS2*NS*PNQ10
        NSGROS=KNS1*SUN*NS*PSNS/(1+KNS1*NS)

* NATIVES COMPETE WITH ALGAE, HYDRILLA FOR SUNLIGHT
* ALGAE AND HYDRILLA USE PART OF INCIDENT SUNLIGHT

* FUNCTIONS CONTROLLING ORTHOPHOSPHATES
OP=INTGRL(ICOP,OPI+OXID-OPUPTK+PRHYOP+PRNSOP+.9*ACPR*PPRESP-CPR*PPGROS...
            +.5*ACPR*PPRESP+.6*ACPR*HPRPAM+.6*.0386*ACPR*FWASTE)
        TOTUPK=CPR*HYGROS
        OPUPTK=.6*ACPR*HYGROS
        SPUPTK=TOTUPK-OPUPTK
* FUNCTIONS CONTROLLING PHOSPHORUS IN SEDIMENTS
SP=INTGRL(ICSP,SPI+.4*ACPR*HYRESP-SPUPTK-CPR*NSGROS+.4*CPR*NSRESP+.1*...
            CPR*PPRESP+.5*ACPR*PPRESP-OXID+.4*ACPR*HPRPAM+.4*ACPR*.036*...
            FWASTE+.036*ACPR*KFN1*FN*AT)

*FUNCTIONS CONTROLLING THE WHITE AMUR
        FN=INTGRL(ICFN,STOCK-KFN1*FN-KFN2*FN)
        FB=INTGRL(ICFB,FASSIM-KFN1*FB*AI-KFN2*FB*AI+STOCK*KBIS)
        FCNSMP=KFB5*AQ10*HY*FN*(KFB2*I+KFB3)


        FASSIM=KFB4*FCNSMP*KFB6
        FWASTE=FCNSMP-FASSIM
        I=FB/FN
        AQ10=.39*EXP(.07*TEMP)

*OTHER FUNCTIONS
SUN=AFGEN(RAD,TIMEY)
PPI=AFGEN(PARTC,TIMEY)*.01
OPI=AFGEN(ORTHO,TIMEY)*.01
PSNS=AFGEN(PLPS,TEMP)
PSHY=AFGEN(PLHY,TEMP)
OXID=AFGEN(SEDPH,TIMEY)
TEMP=AFGEN(DEGR,TIMEY)
TIMEY=AFGEN(DAY,TIME)
NAT=AFGEN(NATFRM,HY)
LP=AMAX1(7580,OP)
        PQ10=.63*EXP(.03*TEMP)
NOSORT
        IF (HY-0.)1,1,2
1       START=SUN
        GO TO 5
2       IF (HY-16.)3,3,4
3       START=SUN*.5
        GO TO 13
4       START=SUN
13      CONTINUE
        IF (HY-16.)5,5,6
* GRAMS OF CARBON ARE CONVERTED TO KILOCALORIES BY MULTIPLYING BY 9
5       JPTOP=SUN-PPGROS*9
        GO TO 7
```

```
6       JRTOP=SUM-9*(HYGROS+PPGROS+PRGROS)
7       CONTINUE
        JONS=JRTOP*XTNC
SORT
TERMINAL
TIMER DELT=1.E-2,FINTIM=10.,PRDEL=.1
METHOD RKSFX
PRINT HYGROS,HYRESP,NSGROS,NSRESP,PPGROS,PPRESP,PRGPHY,PRGPNS,PRRESP,...
        OPJ,OXIP,PRHYOP,PPNSOP,PG10,TEMP,PSNS,PSHY,E*ASTE
PRTPLOT HY(HERB),IU,NS,PP,PR,OP(LP),SP,EN,EB
END
STOP
```

CULTURE TECHNIQUES FOR THE PRODUCTION OF MONOSEX WHITE AMUR

by

A. E. Thomas*

INTRODUCTION

Dr. Jon Stanley initiated investigations into production of monosex white amur (*Ctenopharyngodon idella*) in 1972. (Grass carp is the common name accepted by the American Fisheries Society and this name will be used henceforth.) I assisted Dr. Stanley during the early part of the 1975 spawning season and assumed responsibility for the project in early July 1975, when he transferred to the Cooperative Fishery Research Unit at the University of Maine. The objective of the project was to develop a method that would allow grass carp to be stocked for large-scale field testing of their ability to control aquatic vegetation without danger of reproduction. The major process investigated was that of artificial gynogenesis.

Gynogenesis is the development of an ovum after penetration by a spermatozoan but with no genetic contribution from the male. Our usual procedure in producing monosex or all-female grass carp has been to destroy chromosomes through denaturing the DNA in the sperm with ultraviolet light. We used Israeli carp (*Cyprinus carpio* Var.) males for the sperm donors because the sperm size is similar, and any chromosomal material not destroyed by the ultraviolet irradiation will produce a lethal hybrid. Adult fish of both species were injected with hormones to stimulate the development of eggs and sperm.

The sperm was diluted approximately 1 to 4 with Hank's balanced salt solution without bicarbonate. Thin layers of this solution in uncovered petri dishes were irradiated for 10 min under a ultraviolet lamp (2500 nanometers in wavelength) while being kept in motion by a mechanical oscillator. Grass carp eggs were hand-stripped into pans and weighed, and samples were taken to determine egg numbers. Eggs were then fertilized with irradiated sperm and placed in hatching pots. Hatching began after about 27 hr at 25°C (77°F). Newly hatched diploid fry swam upward, were carried through the overflow drain, and were collected in small trough baskets. Haploid and hybrid fry normally remained in the hatching pot (deformed and less active). Diploid fry have the normal number of chromosomes (same as the mother), probably through retention of the second polar body during meiosis. Only a small percentage of the eggs developed into diploid fry (from 0 to 3.6 percent). The majority of fry were haploids having only half the normal chromosomes. The haploids and the few hybrids produced died within 24 hr. The diploids develop as normal, all-female grass carp.

Another approach to producing monosex grass carp, still in experimental stages, has been that of sex reversal. Diploid fry were fed male sex hormones (methyltestosterone) at various concentrations and durations. Any fish changed to functional males (phenotypic) while still having only female sex chromosomes (genotypic) could be mated with normal females to produce all-female offspring without the reduced survival found with gynogenesis.

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NEW TECHNIQUES AND FACILITIES

Fry-Rearing Boxes

In previous years, newly hatched fry were collected as they moved out of hatching pots and transported to baskets of saran cloth set up in hatchery troughs. The troughs were equipped with paddle wheels and agitators for aeration. The fry were maintained in these baskets for 5 to 7 days before being transported to ponds and were fed egg yolk, brine shrimp, and zooplankton. Considerable manpower was needed for feeding fry and keeping baskets clean. With reconstruction of our wet lab facilities prior to the 1976 spawning season and allocation of troughs to other projects, it became obvious that there would not be enough facilities or manpower to treat the anticipated number of fry in the usual manner. Therefore, we attempted to find a technique for moving the newly hatched fry directly to the ponds, but with protection from predation.

Several rearing boxes were constructed and placed in ponds for this purpose. They consisted of an inner section enclosed by saran cloth and outer sections on either side having wire-screened ends (Figure 1). Fry are introduced into the center section where they feed on small zooplankton entering through the saran cloth. After 5 to 7 days, the fry actively swim to the water surface and over walls to one of the outer sections. Here, they feed on larger zooplankton, still protected from most predators, and eventually swim through the wire mesh into the pond itself. About 3200 fry were placed in one of the boxes, and all had left the center section by 6 days and the outer sections by 2 weeks.

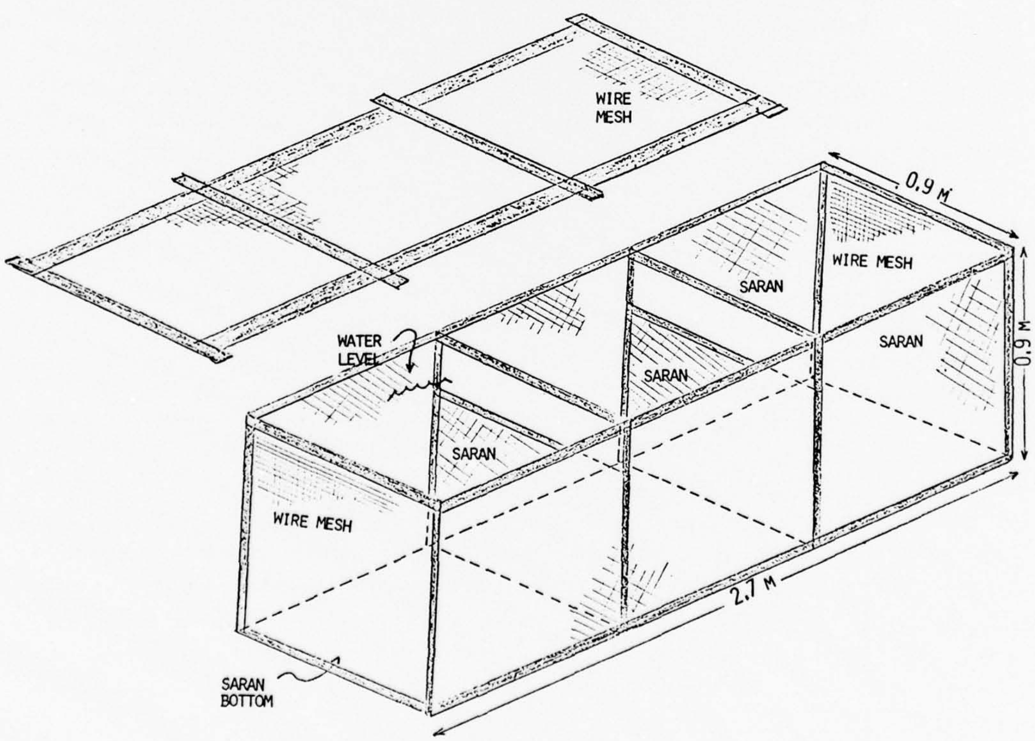

Figure 1. A box for short-term rearing of grass carp fry

Hatching Pots and Other Facilities

The number of hatching pots in use during the 1975 spawning season totaled 10. An additional 14 tanks were purchased early in 1976 in anticipation of the greatly increased numbers of eggs to be taken during the 1976 spawning season. A hatchery room was set up with 17 fiberglass pots, water supplies, troughs, and baskets for collecting fry. Six pots were retained in the original location and one pot was kept as a spare. One end of the hatchery room was set up as laboratory space with the ultraviolet lamps, mechanical shaker, timer, scales for weighing egg totals and samples, refrigerator for storing hormones, irradiated sperm, and various supplies, and a work area for egg fertilization.

The vats used for holding adult grass carp and Israeli carp were set up in orderly sequences with new water supplies, standpipes, screens, and heavy-duty covers with tie-down devices to maintain the fish with minimum losses through escapements or injuries.

Standardized Hormone Treatments of Brood Stock

Considerable variation of the types, levels, and timing of hormone injections has occurred in previous years and by other researchers. Careful testing at the end of the 1975 spawning season and evaluation of previous procedures resulted in a standardized procedure being used in 1976. With this procedure, we injected twice the number of fish as in 1975 and produced five times the number of eggs. The procedure is as follows:

Day 1: Female grass carp are seined up in the morning (ca. 8 a.m.), placed in a hauling unit with an anesthetic (quinaldine), and transported to the holding vats. The fish are individually weighed and injected intramuscularly with 200 IU of human chorionic gonadotropin (HCG) per pound of body weight and placed in covered vats. About 12 hr later (ca. 8 p.m.), the females are again injected with HCG at the rate of 800 IU per pound of body weight.

Day 2: Male Israeli carp are seined up in the afternoon and injected interperitoneally with a solution of 0.2 mg of carp pituitary gland per pound of body weight. At about 8 p.m. (24 hr after last HCG injection), the grass carp females are injected with 5 mg of carp pituitary per pound of body weight. This amount can be reduced to about 3 mg during the peak of the spawning season.

Day 3: Fish are ready to spawn in the early morning with the exact time influenced by the water temperature. Water at 25.5°C (78°F) results in ovulation about 12 hr after the last injection, and cooler water delays ovulation.

1976 SPAWNING SEASON

Examination of "Sex-Reversal" Fish

Gynogenetic grass carp fed methyltestosterone during Fiscal Years 1973 and 1974 were maintained in ponds and fed catfish pellets to speed the time of maturation. Eleven fish fed the male hormone and nine control fish from the 1973 year class reached maturity in June 1976. All fish were females indicating that the hormone levels fed and/or time period involved in feeding were insufficient to cause sex reversal. Attempts to determine the sexes of 14 fish from the 1974 year class were made using an acetocarmine technique. A few of the immature fish were positively identified as females, but the sex of most of the fish could not be distinguished. Several hundred fish from this year's class should reach maturity in June 1977, and the effectiveness of additional hormone levels and feeding durations will be evaluated.

Production of Monosex Grass Carp

Approximately 70 adult female grass carp were acquired from outside sources to supplement the brood stock remaining from other years. All adult fish were routinely fed catfish pellets to improve their physical condition for the 1976 spawning season.

Spawning procedures to produce monosex grass carp began on 24 May 1976, about 2 weeks later than planned due to delays in finishing water supplies and holding facilities. During the period of May 26 to June 28, 115 adult grass carp females were injected with hormones and 88 females produced eggs. This was about twice the number of females successfully spawned in other years and a slight increase in the percentage of fish that spawned to numbers injected with hormones.

Nearly 47 million eggs were collected or about five times those taken previously. No special problems were encountered in the collection and irradiation of Israeli carp milt used in the gynogenetic process. However, only 3245 diploid (normal females) fry were produced from the 47 million eggs, or about 1/10 the number produced in 1975 (Table 1). This low success can be attributed to poor water conditions related to the recently installed pipelines. Large egg takes were killed owing to such problems as insufficient water flows, air locks causing water stoppage, extreme temperature changes, extreme turbidity, low oxygen levels, and possible gas problems in the water. By the time most of these problems were corrected through pipeline repairs, pump replacements, and aeration head boxes, the main spawning season had passed. Figures 2-9 show the general procedures, setup, and equipment for spawning monosex grass carp.

Table 1
Production of Gynogenetic Grass Carp

Year	No. of Eggs	No. of Diploids	Yield, %
1972	40,000	34	0.08
1973	75,000	133	0.18
1974	2,000,000	9,971	0.50
1975	9,128,000	31,840	0.35
1976	46,934,000	3,245*	0.006*

* Fry survivals greatly reduced owing to water quality and quantity.

SURVIVAL OF MONOSEX GRASS CARP IN 0.1-HA PONDS

Six 0.1-ha ponds were used to rear the 1975 fry to the fingerling stage. Three of the ponds had abundant vegetation prior to filling with water with the idea of providing cover for the fry. The other three ponds had essentially no vegetative growth. Five of the ponds, three with vegetation and two without, were filled with water a week or more before the fish were added. The sixth pond was filled with water 2 days before fish were added. All pond surfaces were treated with diesel fuel prior to fry stocking to reduce air-breathing, aquatic predators. Results are shown in Table 2. The wide variation in stocking

Figure 2. Collecting sperm from Israeli carp male

Figure 3. Collecting eggs from grass carp female

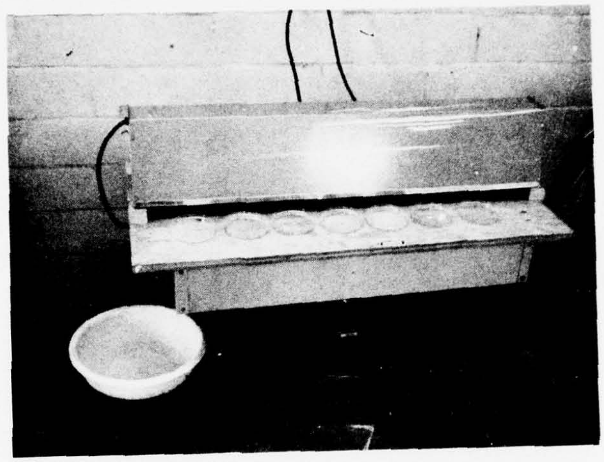

Figure 4. Irradiating Israeli carp sperm with an ultraviolet lamp and mechanical shaker

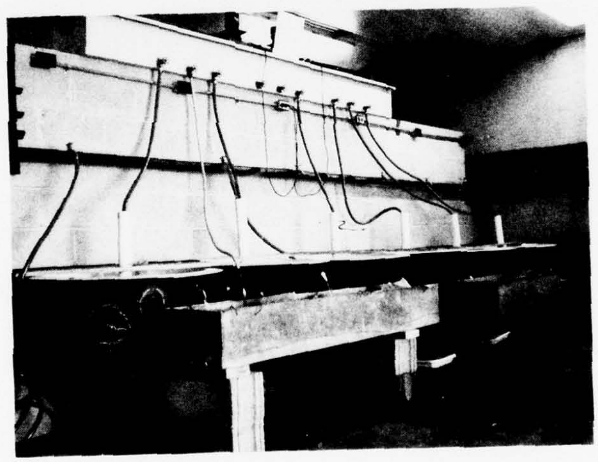

Figure 5. Original hatching pot set up with six pots, head trough, and collecting troughs and baskets

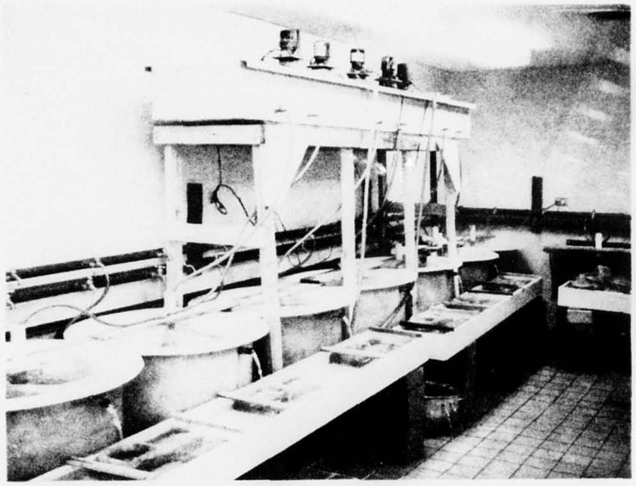

Figure 6. New hatching area with 17 hatching pots, 2 head troughs, and collecting troughs and baskets

Figure 7. Laboratory area containing ultraviolet lamp and shaker, timer, scales for determining egg weights and sampling, refrigeration for irradiated sperm, hormone storage, and work space for egg fertilization

Figure 8. Haploid fry showing deformed yolk material; fry contains only half normal chromosomes and dies within 24 hr

Figure 9. Saran baskets in hatchery trough compartment used for hatching small lots of eggs or in holding fry prior to moving them to the rearing ponds

Table 2
Survival of Monosex Grass Carp in 0.1-ha Ponds from Fry to Large Fingerling Stages Under Various Pond Conditions and Stocking Densities

Pond	Initial Pond Condition	No. of Fry Stocked	Duration days	No. of Fingerling Removed	Percent Survival
A	Weedy, filled early	134	309	51	38.1
B	Weedy, filled early	10,000	305	2412	24.1
C	Weedy, filled early	9,000	300	2857	31.7
D	No weeds, filled early	3,278	299	880	26.9
E	No weeds, filled early	5,000	290	1146	22.9
F	No weeds, newly filled	4,475	287	2695	60.2

rates plus lack of duplications makes these results only observations. However, much better survival occurred in the pond filled shortly before fish stocking. The better survival was probably due to the size of zooplankton available to the fry for food. Vegetation in the ponds did not improve fish survival and resulted in low oxygen levels, due to decay of vegetation and difficulty in harvesting the fish. Stocking densities of the levels used did not affect survival. However, those ponds with heavier fish loads had reduced fish growth.

FISH FOR THE LARGE-SCALE FIELD TEST IN FLORIDA

Our poor success plus the changing policies in Florida have changed our emphasis to one of rearing the 10-15,000 fingerlings from previous years to as large a size as possible to escape predators and to stock them in the Lake Conway system, probably in February 1977. These fish have been stocked into 0.4-ha ponds at the rate of 1500 fish per pond and have been well fed to increase growth. Table 3 lists the groups and gives the estimated weights and lengths in October 1976. Cooler water temperatures will probably prohibit major growth increases between now and February, but the fish will be fed throughout the fall and winter to obtain any growth possible. In addition to the fish listed, an unknown number of survivors from the 1976-year class, estimated to be about 80 cm long, will be available. Several hundred fish from the 1974-year class, used in sex-reversal experiments, would be available in late May should they prove to be all females.

Table 3
Monosex Grass Carp Available for Lake Conway Project
October 1976

Pond(s)	No. of Fish	Age, years	Estimated Weight g	Estimated Length cm
E-7	1500	2-1/2	520	33
E-1, E-4	3000	1-1/2	227	25
E-6, E-8	3000	1-1/2	175	22
E-2, E-5	3000	1-1/2	125	19

MARKING OF GRASS CARP

A reliable, easily detected method for identification of individual fish would be highly desirable for the Lake Conway field test; fish movement between various bodies of water could be determined, and fish within or outside the study area could be identified as to original source. The use of silver nitrate applicators for marking catfish has produced excellent results at this laboratory in terms of retention, flexibility, readability, and low cost. However, this technique has not been thoroughly tested with scaled fishes. Testing has begun on marking white amur with silver nitrate with the hope that a reliable technique can be developed before a planned planting date of February 1977. Three additional techniques will be tested along with silver nitrate as "backup" methods in case the silver nitrate method does not prove reliable with scaled fish. These techniques are: (1) the Floy vinyl tag applied to the gill operculum or under the dorsal fin; (2) a metal (monel) band clipped to the operculum, jaw, or base of fins; and (3) injected pigments.

Preliminary results are as follows: Silver nitrate appears to have good mark retention so far. However, raw areas formed are possible sources for infection and discrete figures possible with catfish would appear possible only with very large fish. Possible solutions may be to identify the fish according to the location of the mark (i.e., planting site one equals mark on left side ahead of the dorsal fin, etc.), and to use a dip treatment (terramycin, furacin, formalin, etc.) on the fish after marking. The Floy tag appears unsuitable for this study where all fish need to retain the marks. Three of seven fish tagged under the dorsal fin had lost the tag by 2 days. The operculum area might give better retention, but a technique has not been worked out to rapidly insert the tag without injuring the fish. The monal tags on the operculums had better retention with 2 of 11 tags being lost within 24 hr. Fifty percent of jaw tags and 100 percent of fin tags (dorsal and pectoral fins) were lost, with some damage to the fins. The nature of the applicator pliers enables only larger fish (. 8 in.) to be tagged without possible operculum and gill damage. Additional problems could result from irritation of the gills by the tag or the effects of rapid fish growth on the small tag.

The technique for injecting pigments into the fish at specific locations using a jet innoculator has been successfully used with striped bass and a few other scaled fish species. An innoculator and a supply of the dye giving the best retention time in other species (National Fast Blue 8 GXM) have been ordered for some time and testing will begin as soon as they arrive.

As a sideline, we have been working with a biologist from the FWS Fish Pesticide Laboratory on electropheretic patterns of white amur from various sources. We may be able to identify fish from our laboratory through blood samples should conventional identification techniques fail.

RESPONSE OF HYDRILLA TO VARIOUS HERBICIDES

by

L. V. Guerra*

INTRODUCTION

Hydrilla, *Hydrilla verticillata* Royle, was first found in 1970 at the Reflection Pool within the Houston Zoo. It has spread at an alarming rate throughout southern-coastal and northern parts of the state (distribution map, Figure 1). Its habitat has been established in the neotropical waters of Texas and

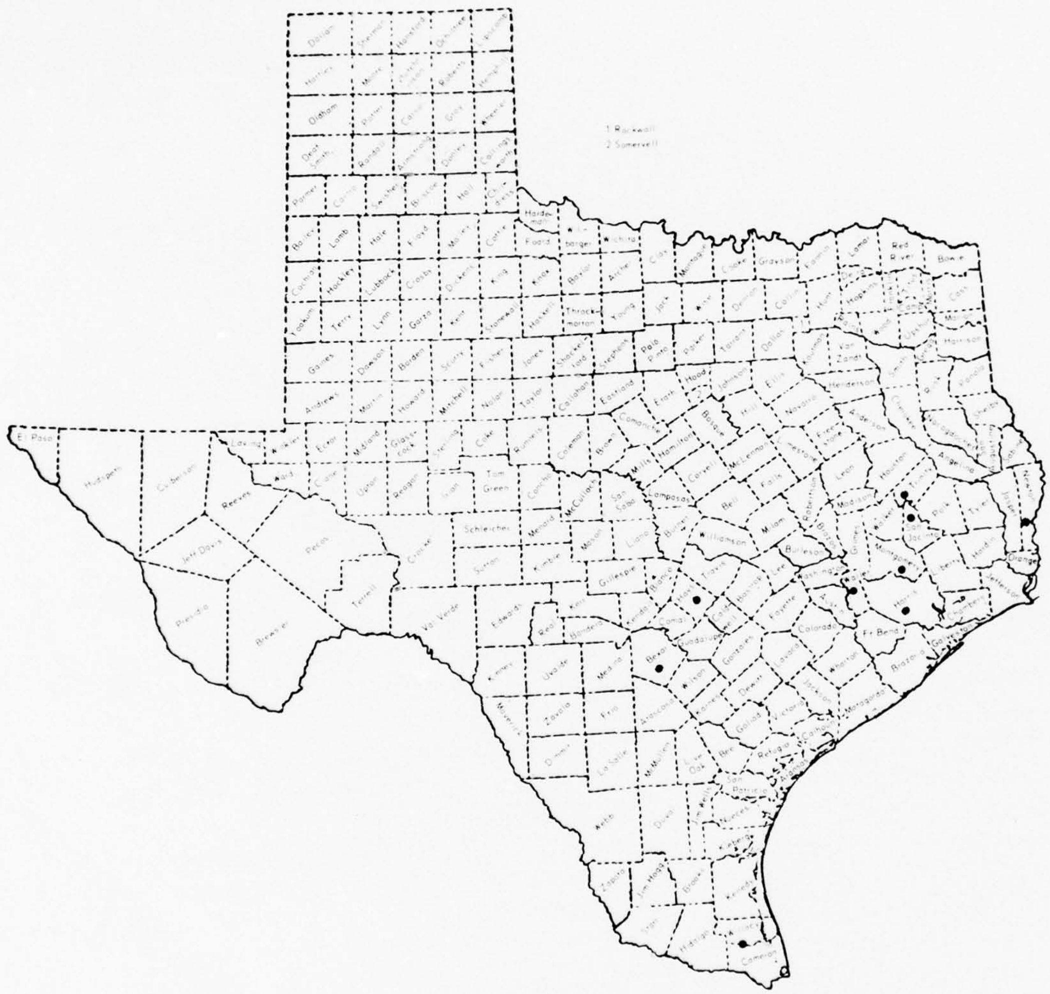

Figure 1. Distribution of hydrilla in Texas

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the slightly acid waters of the deep piney woods of Texas.

The plant, because of tremendous adaptability, fragmenting nature, and asexual and tuber reproductive means, has spread throughout the state. It is even found in constant-temperature spring-fed lakes where tubers are produced throughout the year.

The rapid spread of this plant has caused considerable concern in the state. Various means were found to make the public aware of the dangers and potential of hydrilla spreading. Signs are painted and erected and buoys placed in the vicinity of hydrilla beds. Circulars were also sent to all the state's license dealers and sporting goods stores. We even had a law passed, House Bill 1278, that prohibited the possession, sale, trade, and transfer of noxious aquatic plants. A 1-1/2-min TV spot announcement was also prepared and released to 25 TV stations. It has been estimated that over 30 million people have seen this spot announcement. All of these affirmative actions have been of great value, as many people have been aware of the hydrilla problems.

Lake Livingston is the first major lake where hydrilla has been found. This lake is the source of water supply for domestic, municipal, and industrial use by the city of Houston.

RESEARCH WORK TO DATE

The primary purpose of this short-term research work was to test and evaluate four promising granulated herbicides and the most promising liquid herbicides in aqueous and inverted solutions. The information being sought was to rate and rank the granulated herbicides for total effectiveness, and evaluate the liquid herbicides in its various combinations and compare liquid versus inverted solutions. There was a slight problem with the application of the granular materials; some were "dusty" and some too large. What faults they might have had were made up by the effectiveness of their action. Table 1 shows the relative progressive eradication of the hydrilla. Application work is relatively easy if you have the proper equipment and enough support.

The application of liquid herbicides was another matter. It was difficult to keep the various hoses in an exact place. The aqueous solutions did not present any problems, but inverted formulations did not, in spite of real knowledgeable help, perform as they should. It is apparent that inverting herbicides is a difficult problem that has many variable factors, such as water temperature, mixed ratios, pump performance, and delivery volume.

Part of this work involved measurements into the gradual progressive plant deterioration. This is of importance because the relative efficacy of each herbicide has to be known. This information is of vital interest if a programmed hydrilla eradication or control measures are to be carried out. Chemical analyses for water quality were conducted during this period to determine if zero oxygen content was obtained, or any other water condition that would prove detrimental to our freshwater fisheries program. It was found that clear half-acre test plots are an attractant to fish. Fishermen were quick to realize this facet of our program. Some of our biggest critics are now our biggest supporters.

A change had to be made in our measuring equipment; electronic means did not perform very well due to compacted plants and shallow-water levels. A simple measuring device was constructed to make these differential readings; the readings proved to be very exact. The sudden effectiveness of these granular herbicides can be seen in Plots 1, 2, 3, and 4 (Figures 2-5). A composite drawing (Figure 6) of the monthly averages of all the test plots treated with granular materials is compared for relative effectiveness with the averages for all the liquid formulations. This principal representation encapsulates the whole year's work as it relates to the herbicidal activity of the various tested compounds.

Table 1
Percent Biomass Reduction Relative to Depth

Plot	October	November	December	January	February	March	April	May	June	July	August	September
1	30.8	66.7	100.0	100.0	100	97.4	100.0	100.0	98.0	90	100	90
1A	18.6	66.7	100.0	100.0	100	100.0	100.0	100.0	100.0	97	100	95
2	6.7	83.3	24.3	95.0	100	100.0	100.0	100.0	100.0	100	73	70
2A	9.5	97.9	100.0	100.0	96	96.4	96.8	100.0	98.6	100	87	80
3	6.9	35.3	12.5	100.0	100	95.2	100.0	100.0	100.0	95	93	85
3A	9.5	100.0	14.3	100.0	100	100.0	100.0	100.0	100.0	100	95	10
4	48.5	100.0	100.0	100.0	100	100.0	100.0	100.0	100.0	95	95	92
4A	24.5	100.0	100.0	100.0	100	100.0	100.0	100.0	100.0	100	98	93
5	19.4	69.7	100.0	97.0	97	100.0	100.0	100.0	100.0	97	94	80
5A	14.3	17.8	14.3	19.5	20	88.9	98.7	85.0	75.7	64	50	50
6	17.0	17.2	21.8	52.0	97	100.0	92.1	98.5	86.2	60	46	46
6A	11.1	30.8	17.6	6.6	73	92.8	81.2	92.8	72.7	67	50	48
7	12.0	20.0	44.4	37.5	70	94.1	91.4	97.1	90.0	54	48	46
7A	40.0	25.0	25.0	42.9	100	95.0	97.7	100.0	94.7	83	0	0
8	13.0	15.4	11.8	34.5	97	96.3	91.8	98.4	87.1	54	46	38
8A	20.0	24.2	23.4	25.0	93	96.3	96.6	96.6	86.2	57	0	0
9	14.3	40.0	33.3	35.7	100	96.3	97.1	96.9	87.1	39	44	36
9A	1.5	11.4	36.2	30.0	57	96.8	100.0	100.0	89.7	82	45	40
10	12.1	11.8	7.9	100.0	94	97.7	86.8	95.0	77.3	42	31	28
10A	1.3	21.7	30.8	14.3	74	94.7	97.2	96.4	92.8	75	52	32
11	16.7	8.7	35.8	36.4	100	100.0	96.7	96.7	75.6	46	31	15
11A	5.6	4.0	9.8	29.6	92	86.2	94.7	94.0	88.5	91	35	20
12	9.5	16.7	17.8	33.3	96	95.6	95.5	96.5	72.9	40	36	30
12A	17.4	24.0	42.6	42.9	100	92.3	94.1	96.1	68.0	64	29	20

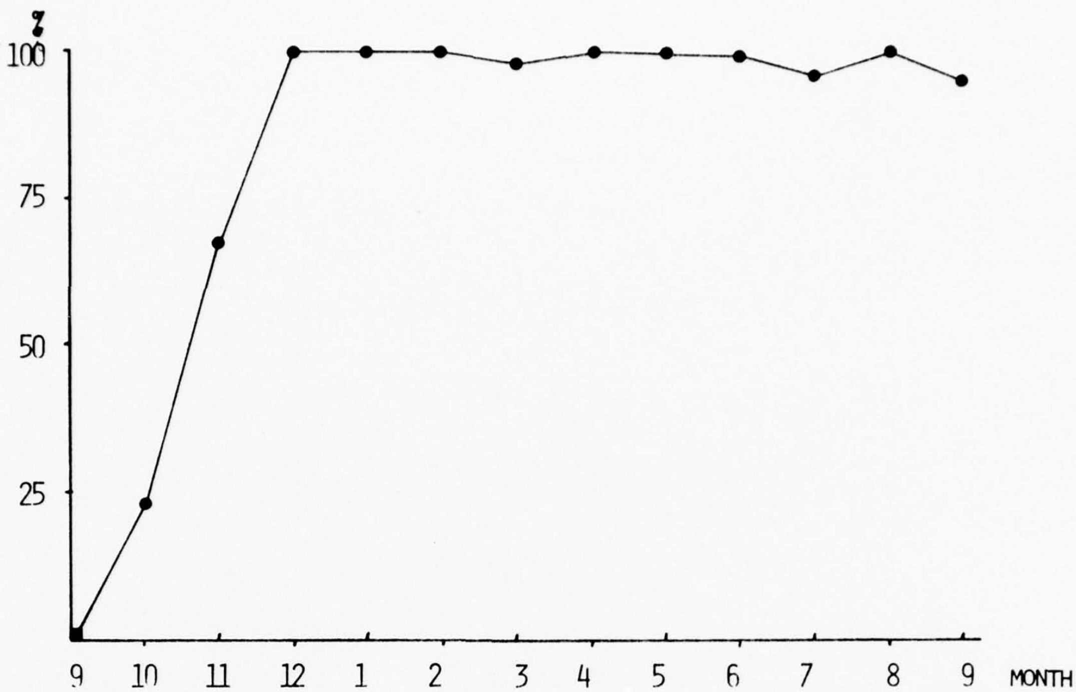


Figure 2. Biomass reduction (%) in Plot 1 treated with Aquathol G (150 lb/AC.)

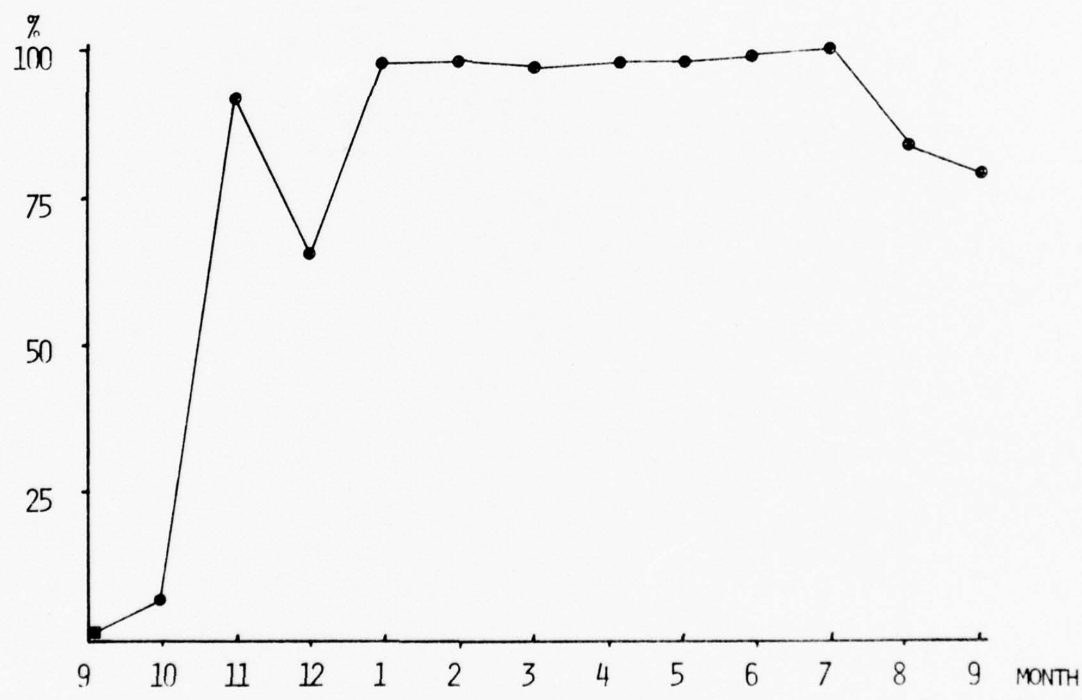


Figure 3. Biomass reduction (%) in Plot 2 treated with Aqua-Kleen-20

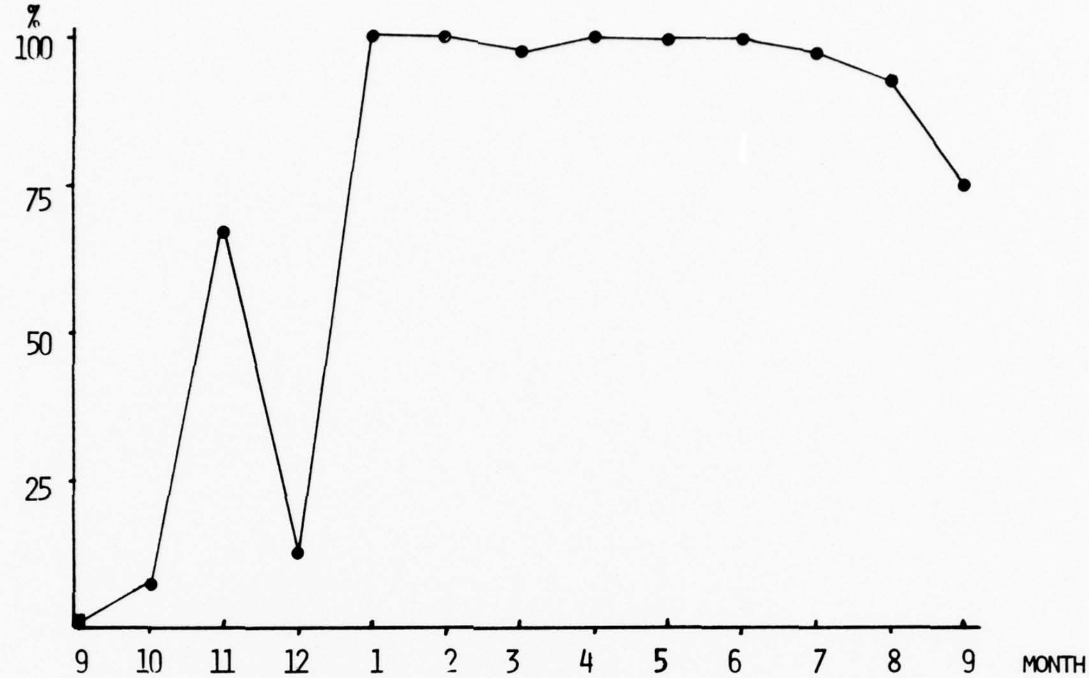


Figure 4. Biomass reduction (%) in Plot 3 treated with Banvel XP

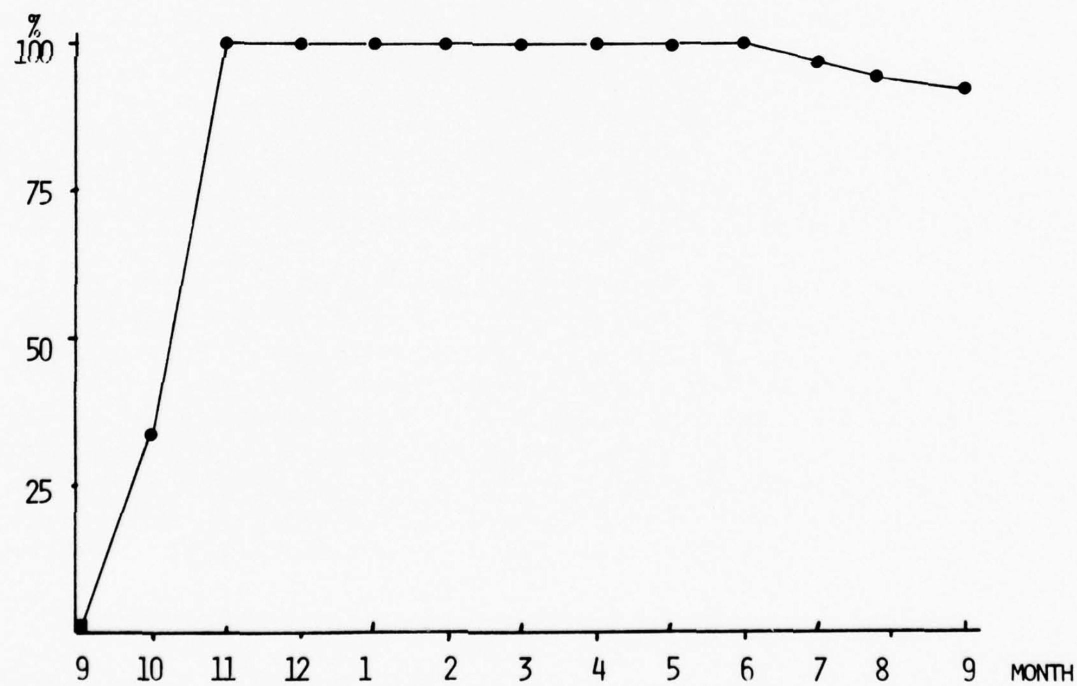


Figure 5. Biomass reduction (%) in Plot 4 treated with Hydout

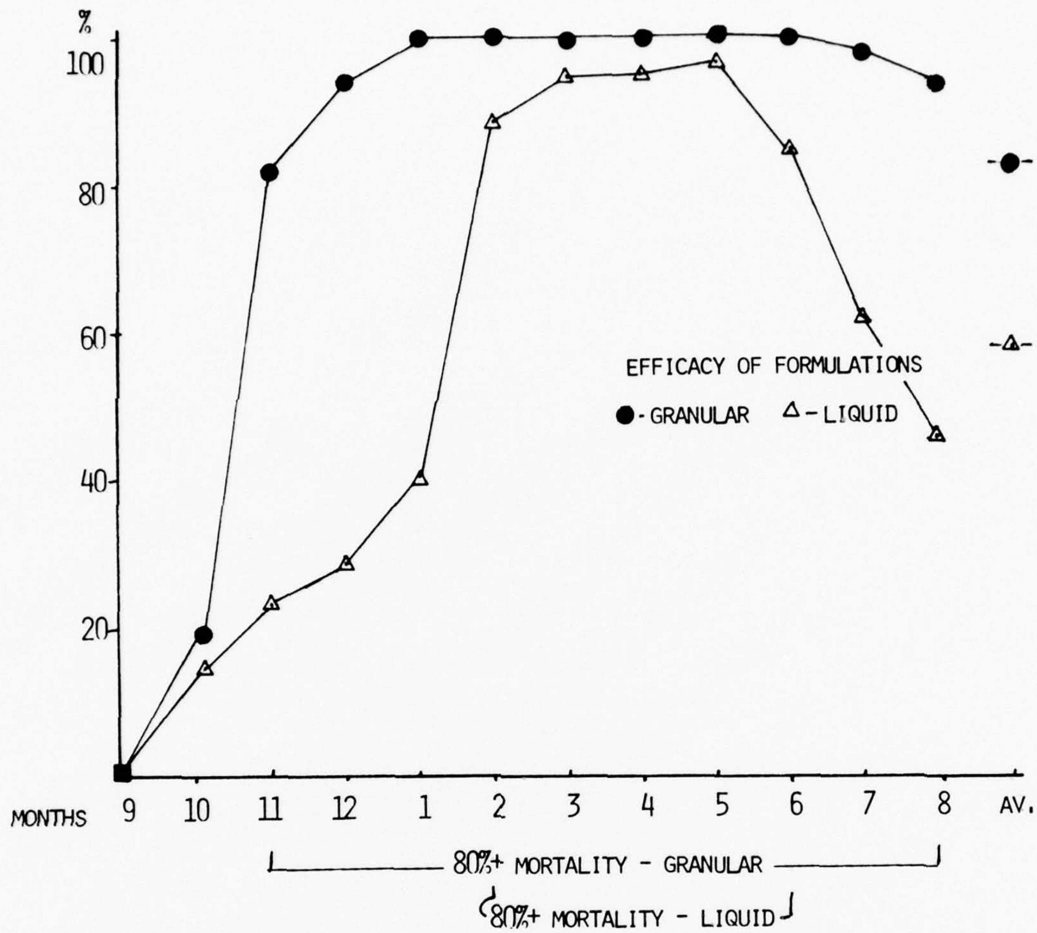


Figure 6. Monthly averages of all test plots treated with granular materials compared with the averages for all liquid formulations

Upon a closer examination, we might assume that dropping over 80 percent of hydrilla in 60 days could present adverse water-quality conditions, but none were observed. Over 90 percent plant destruction was obtained in 90 days, and even higher percentages ranging from 96.5 to 100 percent were sustained for 210 days. The overall yearly average was approximately 85 percent.

A superimposed graph of liquid formulations, both inverted and in aqueous solutions, is also to be found in Figure 6. It was found that liquid formulations were slower to react. It took over 150 days to obtain an over 80 percent plant kill, and then it lasted for only 120 days. The overall yearly average was slightly below 60 percent. In this work, liquid formulations did not perform too well. There now exists a question as to why slower reactions took place. One possible answer is the acidity of the water and the temperature that ensued during the cooler months of the year.

Another factor to be considered is the possibility of overtreatment with the granular herbicides. This avenue of research will be pursued at a later date.

A tuber study, its relative occurrence and production, was also undertaken with the study. Several significant facts are clearly demonstrated. Figure 7a shows that tubers in east Texas are not produced

until December and reach their production peak in January. We then have a gradual decline, and another peak of lesser intensity is prominent in April. We then go into another production decline until June. In July, a last lesser peak is obtained, then a decline. Production peaks can be correlated with the plants' growth and production cycles. The January peak is due to cold water and air temperatures. The plants have flowered in September and October and a senescent period is reached. The lesser production of tubers in February and March verifies this fact. Spring temperatures arrive in late March and April and again a peak is reached in tuber production, which is not necessarily correlated with plant growth above the water's surface. It can be assumed that the plants' growth at this time is in a lateral direction. Another period of lesser tuber production takes place in May and June. The last tuber peak occurs in July, and from an examination of the depth at which the tubers were collected and their size, it can be surmised that they came from young plants. It is apparent that these young plants arose from aerial tubers and plant fragments that grew in May and June.

There is considerable supposition in these theories. There has to be, when tests are conducted away from the laboratory. The growth curves for tubers from control plots (Figure 7b) seem to verify the theories behind tuber production in the treated plots. This simple illustration in relative numbers of tubers completely confirms the theory of the effect of chemical stress upon the hydrilla plant. It also confirms the fact that hydrilla is extremely and rapidly adaptive to all sorts of conditions, in both water and soil.

CONCLUSIONS

Based on the results of the tests, it is concluded that:

a. Hydrilla can be treated with various herbicides to achieve the desired results.

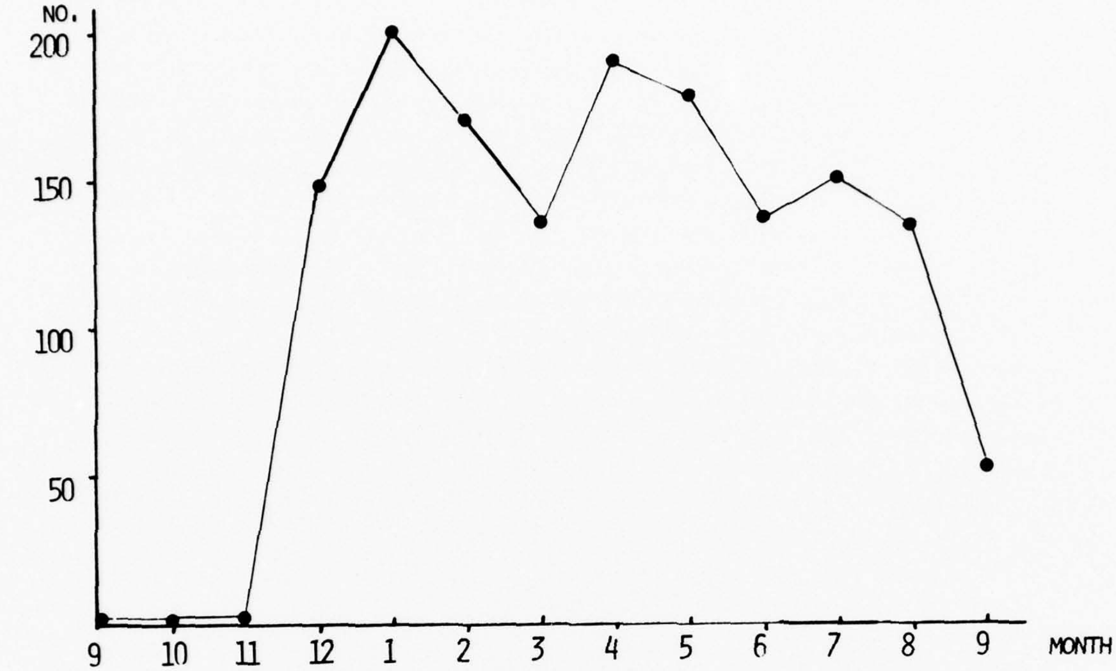
b. The treatment of hydrilla can be programmed to treat large areas and have them ready for peak recreational usage.

c. The ever-decreasing number of tubers from the plants indicates that feasibile control measures can be implemented.

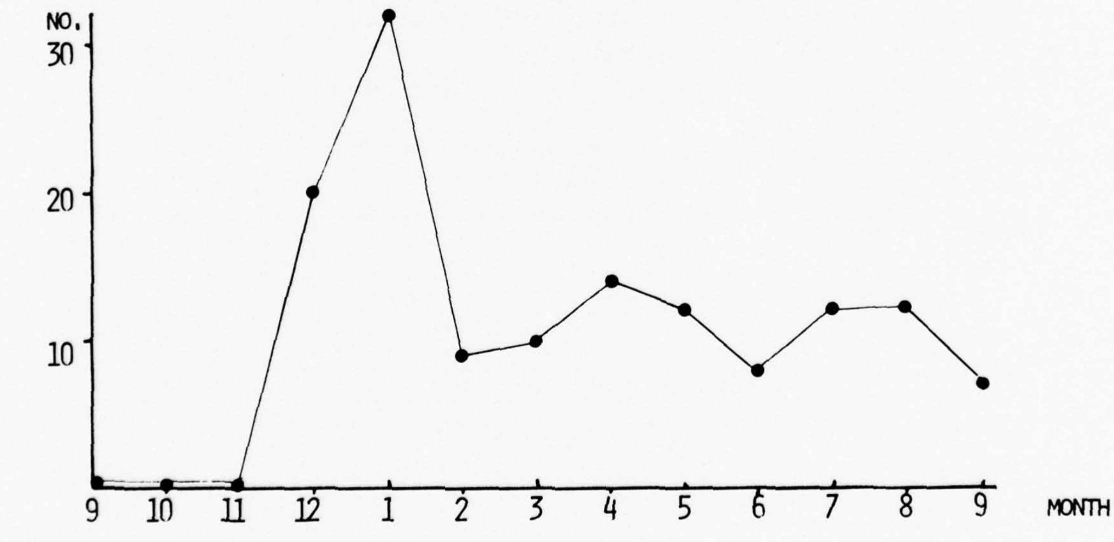
d. Although granular herbicides have done a tremendous job, the possibility of chemical overtreatment exists.

e. Control measures as developed in this research project can prevent the wide dispersal of hydrilla in Texas when less than 2000 acres exist.

f. The possibility of a soil treatment when the plants have been destroyed or beginning to come up should be investigated.



a. Treated plots (24)



b. Control plots (3)

Figure 7. Total tuber production (1 sq ft) in treated and control plots

UPTAKE AND METABOLISM OF DIMETHYLAMINE SALT OF 2,4-D BY FISH

by

H. C. Sikka*

INTRODUCTION

The dimethylamine (DMA) salt of 2,4-dichlorophenoxylacetic acid (2,4-D) is used extensively for controlling aquatic plants such as waterhyacinth and Eurasian watermilfoil. This formulation of the herbicide is relatively nontoxic to fish; the 96-hr TL_{50} values for bluegills (*Lepomis macrochirus*) and channel catfish (*Ictalurus punctatus*) are 160 and 125 ppm, respectively.[1] A knowledge of the degree of accumulation of this herbicide by fish is important if they are to be used for human consumption. The herbicide, if accumulated by fish, may undergo metabolic transformation. The nature of these metabolites must be known in order to assess their possibile toxicity to fish and man.

Presently, very little information is available on the uptake and metabolism of 2,4-D by fish. Rodgers and Stalling[2] studied the uptake and elimination of the ^{14}C-labelled butoxyethanol ester of the herbicide in three species of fish. They reported that the maximum residue concentrations were in the fish within 1 to 2 hr of exposure. Schultz[1] examined the uptake and distribution of ^{14}C-labelled 2,4-D by three species of fish. In these studies, the fish were exposed to the herbicide in plastic pools containing water and a layer of soil at the bottom. The concentration of ^{14}C residues in the edible portion of the fish continued to increase up to 84 days after treatment, but the actual 2,4-D content was negligible, indicating that most of the ^{14}C-residue was a metabolite(s) of 2,4-D. Because of the way the experiment was designed, it is not possible to assess the role of fish in metabolizing the herbicide. Since 2,4-D is readily degraded by microorganisms,[3] it is not clear whether the fish actually metabolized the herbicide or if 2,4-D metabolites were first produced by microorganisms in the water and sediment in the pools and subsequently taken up by fish. In order to assess the ability of fish to metabolize 2,4-D, we studied uptake and metabolism of DMA-2,4-D by bluegills and channel catfish under conditions where microbial degradation of the herbicide in water was minimal.

MATERIAL AND METHODS

Chemicals

^{14}C uniformly ring-labelled 2,4-dichlorophenoxyacetic acid dimethylamine salt (DMA-2,4-D) with a specific activity of 5.38 mCi/mM was purchased from California Bionuclear Corp., Sun Valley, California. This material was judged radiochemically pure by thin-layer chromatography in solvent systems consisting of chloroform and chloroform:methanol (1:1 v/v). Nonradioactive DMA-2,4-D was provided by Amchem Products, Inc., Ambler, Pennsylvania.

Uptake of ^{14}C-DMA-2,4-D

The fish (3-4 in. long) were obtained from the National Fish Hatchery, Orangeburg, South

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Carolina. They were acclimated to laboratory conditions for 2 weeks before being exposed to 2,4-D. The fish were introduced into fresh springwater containing 2 ppm of ^{14}C-DMA-2,4-D. Each liter of water contained two fish and was continuously bubbled with air during the exposure of the fish to the herbicide. Appropriate controls without fish were also included in the study. Two fish were removed from the treated water 8 hr, and 1, 2, 4, 5, and 7 days after treatment, rinsed with clean water three times, and weighed. To determine the amount of radioactivity in the whole body, the fish were cut into small pieces and homogenized with methanol in a Virgis homogenizer. The slurry was shaken for 30 min and centrifuged, and the supernatant was decanted. The residue was reextracted with 80 percent methanol. After centrifugation, the two extracts were combined, and the amount of ^{14}C in the pooled extract was determined by liquid scintillation counting. The amount of ^{14}C in the tissue residue was determined by solubilizing it in NCS tissue solubilizer (Amersham Searle Corp.) for 48 hr at 50° C.[4] Glacial acetic acid (0.003 ml/ml of solubilizer) was added to the solubilized tissue and the solution was counted for ^{14}C using scintillation fluid containing Triton X-100. The samples were stored overnight at 4° C in the dark before counting. The radioactivity in the methanol extract and in the tissue residue was combined to calculate the ^{14}C concentration in the fish.

To determine the distribution of radioactivity in the fish tissues, the fish were removed from the treated water, rinsed with clean water, and separated into two portions, one containing edible flesh, the other head and viscera. The amount of radioactivity in the edible flesh was determined using the same procedure described for the whole body, while that in the head and viscera portion was measured following solubilization in NCS tissue solubilizer.

Metabolism of 2,4-D

To study the metabolism of 2,4-D by the fish, 30 fish were exposed to 2 ppm of ^{14}C-DMA-2,4-D. After 7 days, the fish were removed, rinsed with fresh water, and homogenized with methanol. The homogenate was filtered, and the residue was then extracted with 80 percent methanol. The extracts were combined, and the methanol in the extract was removed under vacuum. The remaining aqueous solution was acidified to a pH of approximately 2 and extracted with chloroform. The chloroform extracts were combined and the ^{14}C in the organic and aqueous phases was determined. The chloroform extract was concentrated and chromatographed on thin-layer silica gel plates in the following solvent systems (i) chloroform and (ii) *n*-chloroform:methanol (1:1). After drying, the chromatograms were scanned for detection of radioactivity in a Nuclear-Chicago Actigraph. Authentic 2,4-D was co-chromatographed for comparison with unknown metabolites in the extract.

RESULTS

Uptake and Distribution of ^{14}C-2,4-D (DMA) by Fish

i. *Bluegills*: Table 1 shows the concentration of ^{14}C (expressed as 2,4-D equivalent) in edible flesh, head plus viscera, and total body at various times after exposure to water containing 2 ppm of 2,4-D. The concentrations of ^{14}C-labeled residues reported represent the sum of the radioactivity in the methanol extract and in the extracted residue. The concentration of ^{14}C in the whole fish reached a maximum of about 1 ppm 24 hr after treatment. Longer exposure up to 7 days did not result in a significant change in the total ^{14}C concentration. The data showed that the fish removed very small amounts of 2,4-D from the treated water; less than 0.5 percent of the total amount of the herbicide was absorbed by the fish during a 7-day exposure. At all sampling times, a major portion of the radioactivity

Table 1
Concentration (ppm) of ^{14}C (2,4-D DMA Equivalent) in Bluegills Exposed to Water Containing 2 ppm ^{14}C 2,4-D DMA*

Time After Exposure	Edible Flesh	Head + Viscera	Total Body
6 hr	0.071	1.084	0.528
1 day	0.078	2.201	0.931
4 days	0.114	1.712	0.868
7 days	0.065	1.501	0.651
14 days	0.096	1.618	0.819

* Two fish analyzed per time interval.

absorbed by the fish was associated with the head plus viscera portion, which accounted for slightly less than 50 percent of the total fish weight. At all sampling times, less than 5 percent of the total ^{14}C in the fish was associated with the flesh.

ii. *Channel Catfish*: The concentration of ^{14}C (expressed as 2,4-D equivalent) in catfish exposed to 2 ppm of ^{14}C-2,4-D is shown in Table 2. As in the case of bluegills, the concentration of radioactivity in the fish reached an equilibrium within 24 hr after treatment. However, catfish removed a smaller amount of the herbicide from the water than bluegills. The maximum concentrations of ^{14}C in catfish and bluegills 24 hr after treatment were 0.20 and 0.93 ppm, respectively.

Table 3 shows the concentration of ^{14}C in edible flesh, head plus viscera, and total body 2 and 7 days after exposure to ^{14}C-2,4-D. As noticed in bluegills, a major portion of the ^{14}C removed by the fish was associated with the head plus viscera portion. Edible flesh accounted for about 10 percent of the total ^{14}C-residue in the fish.

Table 2
Uptake of ^{14}C 2,4-D DMA by Catfish Exposed to 2 ppm of the Herbicide

Time After Exposure	Concentration in Whole Body (ppm Expressed as 2,4-D Equivalent)
8 hr	0.17
1 day	0.20
2 days	0.20
3 days	0.16
4 days	0.24
5 days	0.25
6 days	0.18
7 days	0.25

Table 3
Distribution of ^{14}C 2,4-D in Catfish
Exposed to 2 ppm of the Herbicide

Time After Treatment, days	Flesh	^{14}C Concentration (ppm Expressed as 2,4-D Equivalent) Head + Viscera	Whole
2	0.097		0.25
7	0.064	0.59	0.32

Metabolism of 2,4-D by Bluegills and Catfish

In the case of bluegills, methanol extracts of edible flesh and head plus viscera were analyzed by thin-layer chromatography to determine the nature of radioactivity, whereas in the case of catfish, the extracts of the whole fish were analyzed. Thin-layer chromatographic analysis of the extracts from the bluegills or catfish exposed to ^{14}C-2,4-D for 7 days showed that all the ^{14}C in the methanol extractable fraction was present as a single compound, which co-chromatographed with authentic ^{14}C-2,4-D in two different solvent systems. (Rf 0.04 in chloroform and 0.71 in chloroform-methanol, 1:1.) In contrast to microorganisms which are known to readily degrade 2,4-D,[3] bluegills or catfish do not appear to be capable of metabolizing the herbicide.

^{14}C-Analysis of the Treated Water Containing Fish

The nature of the ^{14}C remaining in the water containing the fish was also determined. After removal of the fish, the water was acidified to pH 2 with 1 N HCl and extracted twice with ether. The ether extracts were combined, and the amount of radioactivity in the organic and aqueous phases was determined. The ether extract was concentrated, and aliquots were chromatographed on thin-layer silica gel plates as described previously. The results showed that essentially all of the radioactivity in the water bathing the fish was extractable with ether. Thin-layer chromatographic analysis of the ether extract indicated the presence of only one spot with an Rf value corresponding to that of authentic ^{14}C-DMA-2,4-D.

Metabolism of 2,4-D by Bluegills Following Intraperitoneal Injection

On account of low uptake of 2,4-D by bluegills exposed to the herbicide in water, it was decided to examine the ability of the fish to metabolize 2,4-D administered by intraperitoneal injection. ^{14}C-DMA 2,4-D was dissolved in distilled water, and 50 to 100 μl of the solution were injected into the peritoneal cavity. The fish were transferred to fresh water, which was periodically monitored for ^{14}C. At the end of the experiment, the water was acidified to pH 2 and extracted with chloroform, and the chloroform and water phases were counted for radioactivity. The chloroform extract was concentrated and analyzed by TLC as described earlier.

It was observed that 2,4-D was rapidly excreted from the fish following intraperitoneal injection. About 90 percent of the initial ^{14}C was excreted by the fish within 6 hr of treatment (Table 4). When the

Table 4
Time Course of ^{14}C Excretion Following Intraperitoneal Injection of ^{14}C 2,4-D DMA

	^{14}C Excreted (% of ^{14}C Injected)*	
Time After Injection, hr	1.0 ppm Dosage	2.5 ppm Dosage
0-1	62.4	57.7
1-3	22.1	24.0
3-6	4.2	7.2
Total	88.7	88.9

* Average of two fish.

water was acidified and extracted with chloroform, essentially all of the ^{14}C was present in the chloroform extract. Thin-layer chromatography of the chloroform extract in two different solvent systems revealed only the presence of 2,4-D.

DISCUSSION

The results of this study show that the uptake of DMA-2,4-D by bluegills and channel catfish is very small, and the herbicide does not bioaccumulate in the fish. The residues of 2,4-D detected in the fish in the studies are below the established tolerance limit for 2,4-D of 1.0 ppm in fish.[5] A low uptake of DMA-2,4-D by the fish may be explained by the fact that the herbicide in the water was mostly present in an ionized form, which is less likely to partition from water into fish. Similar results have been reported on the uptake of other water-soluble pesticides and their metabolites.[4,6]

Our findings demonstrate that the fish were not able to metabolize 2,4-D. In contrast to our results, Schultz[1] reported that most of the radioactivity in fish exposed to ^{14}C-DMA-2,4-D was present as metabolites of the herbicide. However, his studies did not indicate whether the ^{14}C-metabolites detected in the fish were produced by the fish themselves or if the 2,4-D was metabolized outside the fish as a result of microbiological or nonbiological reactions and the metabolites were then absorbed by the fish. Since 2,4-D is known to be readily degraded by microorganisms, we speculate that the ^{14}C-metabolites found in the fish in the studies reported by Schultz[1] originated in the water surrounding the fish as a result of microbial activity and were subsequently removed by the fish. The results of our studies support this speculation. Under the conditions of our experiments where no degradation of ^{14}C-2,4-D was observed in the water, all the radioactivity in the fish was present as the unchanged herbicide.

SUMMARY

Bluegills and channel catfish removed less than 0.5 percent of ^{14}C-DMA-2,4-D when exposed in aquaria to water containing 2 ppm of the herbicide. The maximum concentration of 2,4-D in the fish was reached within 24 hr of treatment; thereafter, it did not change significantly up to 7 days. Catfish

removed a smaller amount of the herbicide from the water than bluegills. No evidence for bioaccumulation of 2,4-D in the fish was noted during the duration of the experiment. A major portion of the radioactivity absorbed by the fish was associated with the head plus viscera portions with relatively low concentrations in the edible flesh. The fish did not metabolize 2,4-D during the 7 days following treatment. Bluegills administered ^{14}C-DMA-2, 4-D by intraperitoneal injection excreted 90 percent of the herbicide within 6 hr of treatment.

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CHARACTERIZATION AND EVALUATION OF POLYMERS CONTAINING HERBICIDES AS PENDENT SIDE CHAINS

by

F. W. Harris*

INTRODUCTION

Controlled-release, herbicide-polymer formulations that extend the control of aquatic weeds have been developed.[1,2] Fenac-polyethylene and fenac-ethylcellulose formulations have been developed and studied in this laboratory.[3,4] In these formulations the herbicide is physically incorporated in a polymeric matrix and release occurs by diffusion. Although these formulations have considerable potential, a drawback to their production and use is the large amount of inert polymer carrier (70-90 percent w/w) that must be employed. The development of new herbicide-polymer formulations that contain a high percentage of herbicide is highly desirable.

One approach to obtaining these formulations has been the synthesis of polymers that contain herbicides as pendent side chains. In the first part of this study, polymers that contain 80-90 percent 2,4-dichlorophenoxyacetic acid (2,4-D) or 2-(2,4,5-trichlorophenoxy)propionic acid (silvex) were prepared from a series of vinyl monomers. The monomers, i.e. vinyl 2,4-dichlorophenoxyacetate (1a), vinyl 2-(2,4,5-trichlorophenoxy)propionate (1b), 2-acryloyloxyethyl 2,4-dichlorophenoxyacetate (2a), 2-acryloyloxyethyl 2-(2,4,5-trichlorophenoxy)propionate (2b), 2-methacryloyloxyethyl 2-(2,4,5-trichlorophenoxy)propionate (3b), 4-acryloyloxybutyl 2,4-dichlorophenoxyacetate (4a), and 4-acryloyloxybutyl 2-(2,4,5-trichlorophenoxy)propionate (4b), were polymerized by bulk-, solution-, and emulsion-free-radical techniques (Figure 1). The polymerizations were enhanced by low initiator concentrations and mild conditions. Polymers 5a-8b have intrinsic viscosities as high as 2.03 and can be cast into tough, transparent films.[5-7]

The polymer systems were designed so that herbicide release would occur by the slow, sequential hydrolysis of the herbicide-polymer chemical bonds. In this first series of polymers, the length of the linkage connecting the herbicide to the polymer backbone was varied. It was postulated that increasing the length of the pendent side chain would enhance the hydrolysis of the herbicide-polymer ester bond, since the bond would be removed from the hydrophobic backbone and less sterically hindered.

In another attempt to vary the rate of hydrolysis, copolymerizations of 2-acryloyloxyethyl 2,4-dichlorophenoxyacetate (2a) and 2-acryloyloxyethyl 2-(2,4,5-trichlorophenoxy)propionate (2b) with vinyl monomers that would vary the hydrophilicity of the resulting copolymer backbone were carried out. For example, the monomers 2a and 2b were copolymerized with trimethylamine methacrylimide (10) and 1,1-dimethyl-(2-hydroxypropyl)amine methacrylimide (11), hydroxyethyl acrylate (12), and acrylic acid (13) (Figure 2). These materials contain functional groups which give the corresponding copolymers greater hydrophilicity.

The major objectives of this research were: (1) to complete our study of the hydrolysis of polymers containing 2,4-D which was initiated under Contract DACW73-74-C-0001; (2) to determine the effects of pH on the polymers' rates of hydrolysis; (3) to synthesize and polymerize a new series of vinyl

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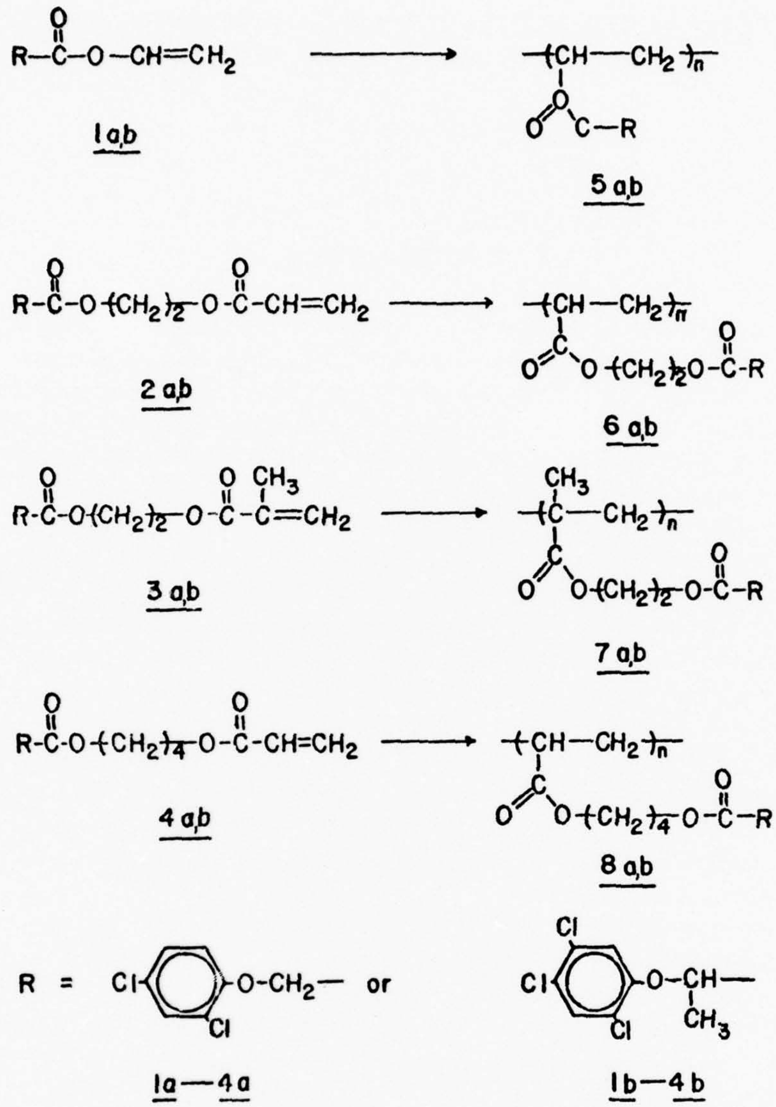

Figure 1. Polymerization of monomers containing 2,4-D and silvex

monomers containing 2,3,6-trichlorophenylacetic acid (fenac); and (4) to determine the rates of hydrolysis of the polymers containing fenac under carefully controlled conditions.

RESULTS AND DISCUSSION

Syntheses of Vinyl Monomers Containing Fenac

The syntheses of five vinyl monomers containing fenac were carried out. Vinyl 2,3,6-trichlorophenylacetate (15) was prepared in high yield by the mercuric acetate-sulfuric acid catalyzed, vinyl-interchange reaction between vinyl acetate and fenac (14) (Figure 3). Four monomers were

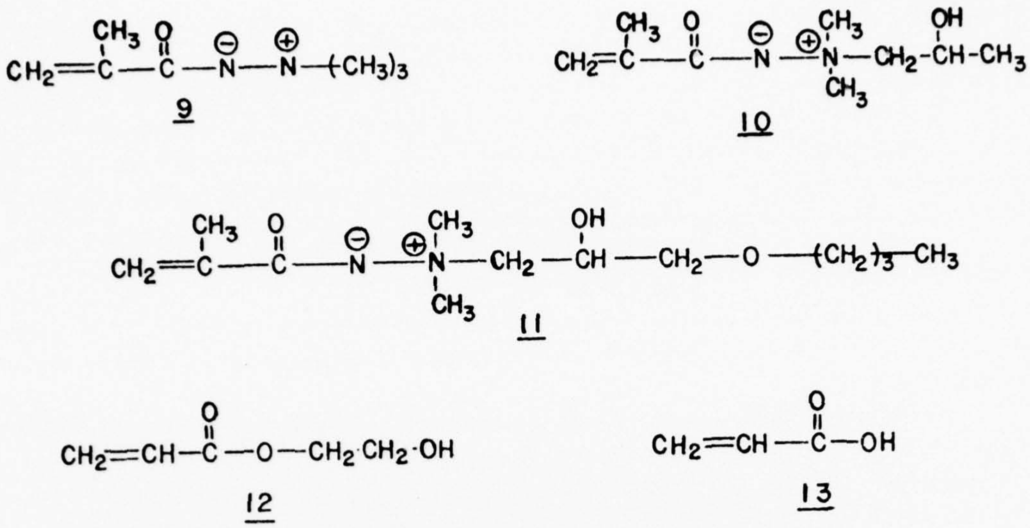

Figure 2. Hydrophilic comonomers

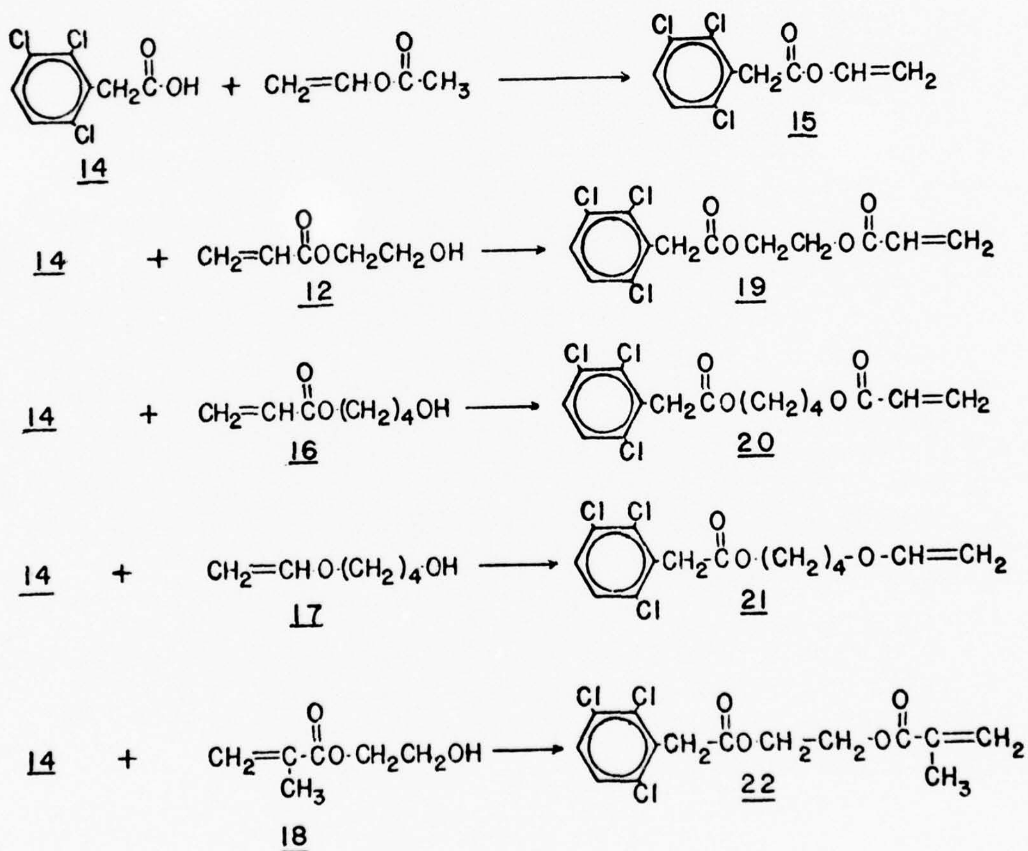

Figure 3. Synthesis of vinyl monomers containing fenac

synthesized by the condensation of vinyl alcohols with fenac in the presence of the dehydrating agent dicyclohexylcarbodiimide (Figure 3). Thus, the reactions of fenac with 2-hydroxyethyl acrylate (12), 4-hydroxybutyl acrylate (16), 4-hydroxybutyl vinyl ether (17), and 2-hydroxyethyl methacrylate (18) gave 2-acryloyloxyethyl 2,3,6-trichlorophenylacetate (19), 4-acryloyloxybutyl 2,3,6-trichlorophenylacetate (20), 4-vinyloxybutyl 2,3,6-trichlorophenylacetate (21), and 2-methacryloyloxyethyl 2,3,6-trichlorophenylacetate (22), respectively. The purification of the monomers was difficult because of their tendency to undergo spontaneous polymerization.

Polymerization of Vinyl Monomers Containing Fenac

The polymerization of vinyl 2,3,6-trichlorophenylacetate (14) was carried out by a bulk-free-radical technique (Figure 4). Polymer 23 is soluble in chlorinated hydrocarbon solvents and has an inherent viscosity of 0.21.

The polymerization of 4-vinyloxybutyl 2,3,6-trichlorophenylacetate (21) was attempted by both solution- and bulk-free radical techniques. No polymer, however, could be isolated from the solution polymerizations. The bulk polymerizations afforded very low yields (<5 percent) of polymer 24.

The polymerization of 2-acryloyloxyethyl 2,3,6-trichlorophenylacetate (19) was carried out by bulk- and solution-free radical methods. In this case, the bulk polymerizations resulted in chloroform-insoluble, cross-linked gels. The solution polymerizations also yielded a large amount of cross-linked material and a very low yield (<8 percent) of soluble polymer.

The bulk polymerization of 4-acryloyloxybutyl 2,3,6-trichlorophenylacetate (20) afforded a 52 percent yield of the gummy polymer 26. The white polymer has an inherent viscosity of 0.35.

The polymerization of 2-methacryloyloxyethyl 2,3,6-trichlorophenylacetate (22) was also carried out by a bulk-free radical technique. However, the polymerization gave a very low yield (< 10 percent) of polymer 27. A summary of the polymerization studies is given in Table 1.

Hydrolysis of Polymers Containing 2,4-D at pH 7

Our study of the hydrolysis of poly(vinyl 2,4-dichlorophenoxyacetate) (5a) poly(2-acryloyloxyethyl 2,4-dichlorophenoxyacetate) (6a), an 87:13 copolymer of 2-acryloyloxyethyl 2,4-dichlorophenoxyacetate and trimethylamine methacrylimide, poly(1-methyl-2-acryloyloxyethyl 2,4-dichlorophenoxyacetate), and poly(4-acryloyloxybutyl 2,4-dichlorophenoxyacetate) (8a), which was initiated under Contract DACW73-74-C-0001, was completed. The study was carried out with polymer samples that were extracted with ethanol to remove unreacted monomers and then ground and sieved to a particle size of 125-400μ. One-gram replicates were immersed in 300 ml of distilled water (pH 7.0) at 30°C, and the amount of herbicide released from each was determined periodically by spectrophotometric analysis. The amounts shown in Figure 5 are the averages of three replicates. The study was continued for 340 days at which time the copolymer samples had released an average of 23 mg of 2,4-D. The homopolymers, however, failed to undergo hydrolysis. These results indicate that in order for a polymer containing pendent herbicide substituents to undergo hydrolysis at 30°C and pH 7, it must also contain pendent hydrophilic residues, such as aminimide groups.

Hydrolysis of Polymers Containing 2,4-D and Fenac at pH 8

A study of the hydrolysis of poly(vinyl 2,3,6-trichlorophenylacetate) (23), poly(vinyl 2,4-dichlorophenoxyacetate) (5a), poly(2-acryloyloxyethyl 2,4-dichlorophenoxyacetate) (6a), and a 75:25

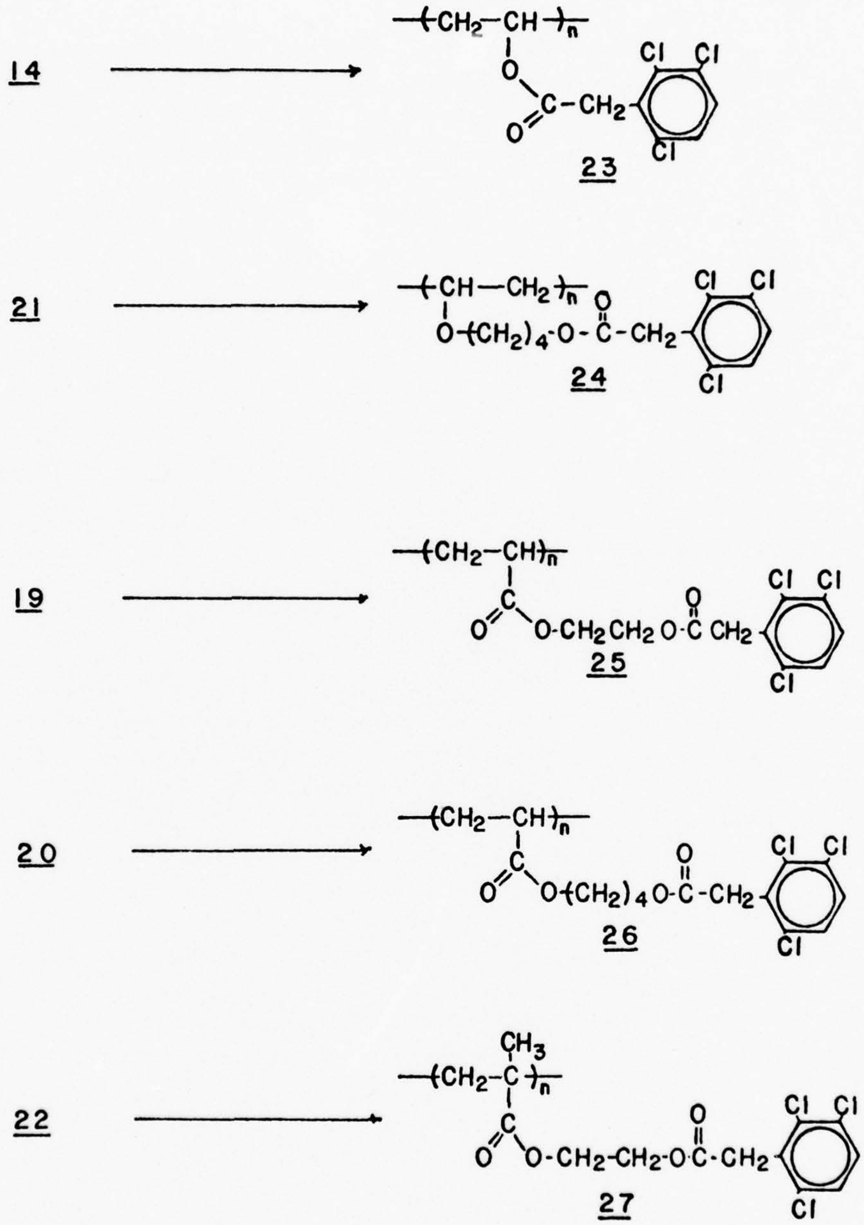

Figure 4. Polymerization of vinyl monomers containing fenac

Table 1
Polymerization Conditions for Vinyl Monomers Containing Fenac

Monomer	Method	Reaction Temperature °C	Reaction Time hr	Monomer* %	AIBN** %	Results
21	Solution†	80	1.50	25	0.025	No polymer formed
21	Solution	80	3.00	25	0.025	No polymer formed
21	Bulk	80	2.00	--	0.100	<10 percent soluble polymer
19	Bulk	75	3.00	--	0.100	Cross-linked gel
19	Bulk	75	1.00	--	0.100	Cross-linked gel
19	Solution	75	0.08	25	0.025	<8 percent soluble polymer
20	Bulk	75	2.00	--	0.100	52 percent yield polymer
22	Bulk	75	0.16	--	0.100	<10 percent soluble polymer

* Weight-to-volume percent where applicable.
** Azobisisobutyronitrile; concentration weight-to-volume percent for solution method and weight-to-weight percent for bulk method.
† Benzene solvent.

copolymer of 2-acryloyloxyethyl 2,4-dichlorophenoxyacetate and trimethylamine methacrylimide at pH 8.08 was carried out. The polymers were immersed in a buffer solution containing boric acid and sodium hydroxide at 30°C. The amount of herbicide released was determined periodically by spectrophotometric analysis. The data show that only the copolymer which contains hydrophilic aminimide residues undergoes significant hydrolysis under these conditions (Figure 6). In fact, even the rate of hydrolysis for this copolymer is not significantly different than that observed at pH 7.

Copolymerization Studies

Since the initial release rate studies indicated that in order for the polymers containing herbicides to undergo hydrolysis they must also contain hydrophilic substituents, a detailed study of the copolymerization of the previously prepared monomers was carried out (Figure 7, Tables 2, 3). The hydrophilic comonomers used were acrylic acid, methacrylic acid, N-vinyl-2-pyrrolidone, and trimethylamine methacrylimide.

The copolymerization of vinyl 2,4-dichlorophenoxyacetate (1a) with acrylic acid (13) using a mole ratio of 1a:13 of 80:20 was carried out by both solution- and bulk-free radical techniques. The solution copolymerizations resulted in cross-linked, insoluble gels. The bulk-free-radical method afforded cross-linked polymer and a low yield (<10 percent) of chloroform-soluble polymer (Table 2).

The solution-free-radical copolymerization of 2-acryloyloxyethyl 2,4-dichlorophenoxyacetate (2a) with 13 using a mole ratio of 2a:13 of 80:20 afforded the copolymer 29 in 63 percent yield. The polymer is soluble in chlorinated hydrocarbon solvents and has an inherent viscosity of 0.70. Infrared and elemental analyses indicate that the copolymer contains 20 percent acrylic acid.

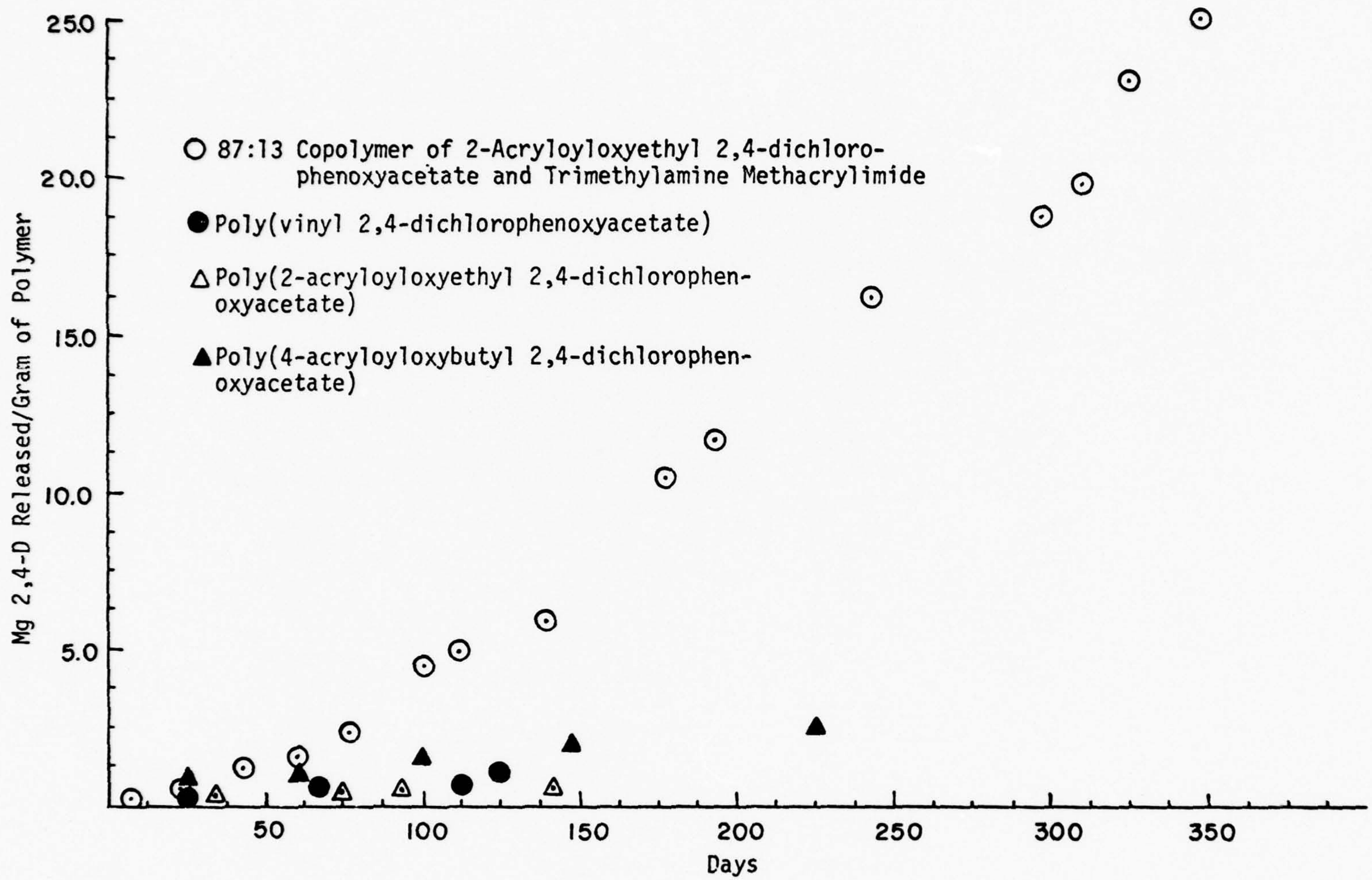

Figure 5. Hydrolysis of polymers containing 2,4-D at pH 7

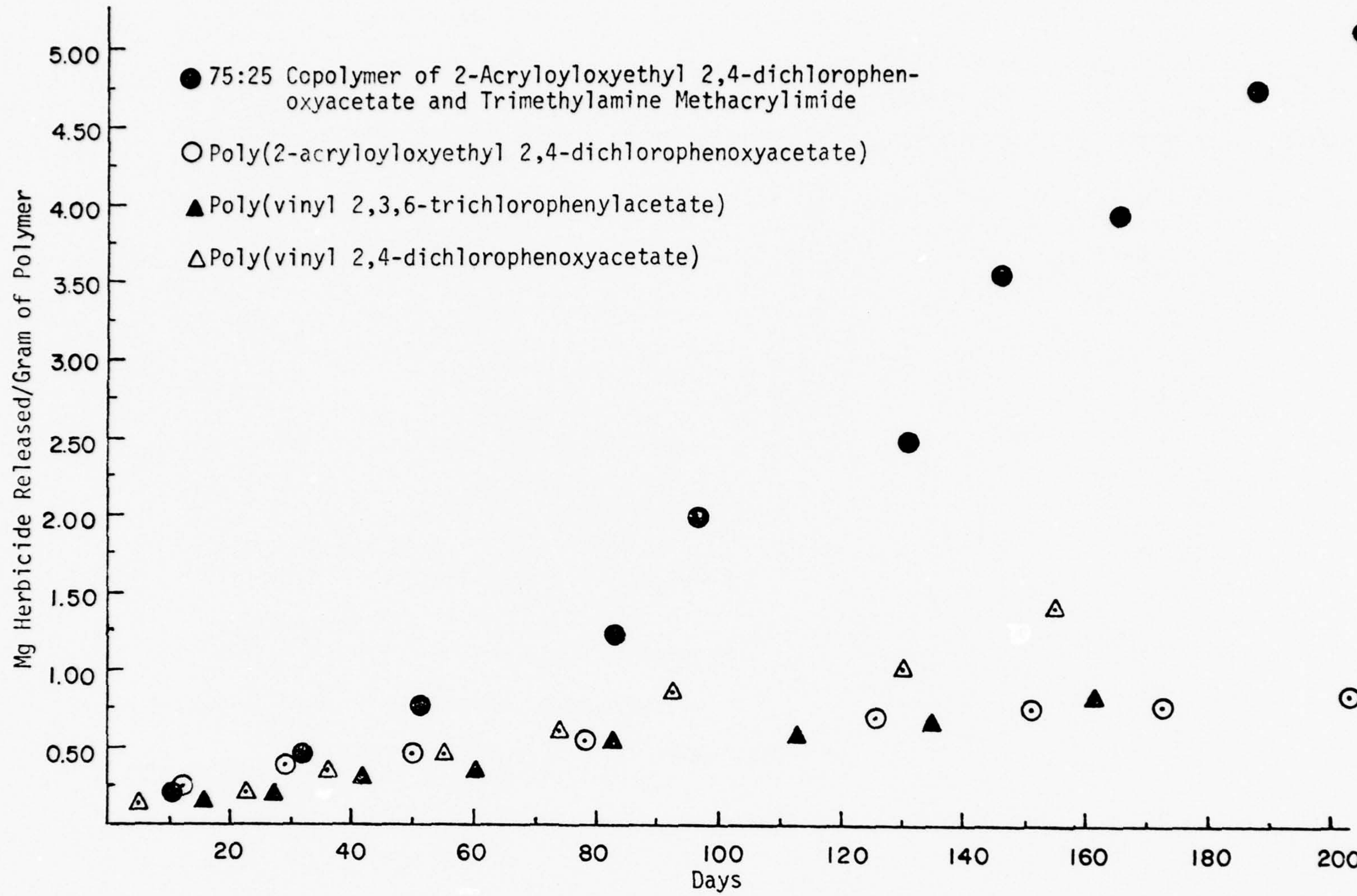

Figure 6. Hydrolysis of polymers containing 2,4-D and fenac at pH 8

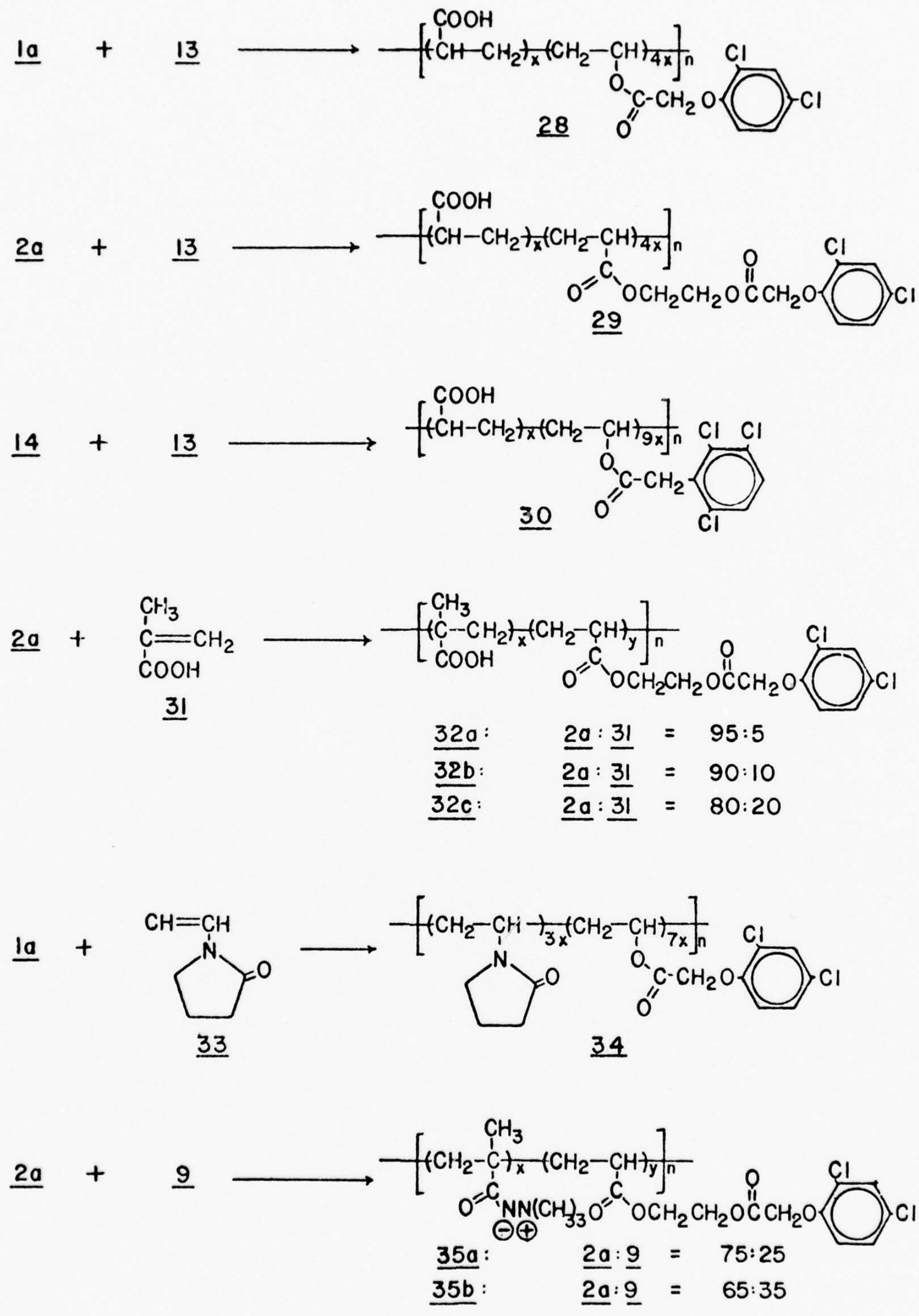

Figure 7. Copolymerization of vinyl monomers

Table 2

Summary of 2,4-Dichlorophenoxyacetate Copolymers: Methods and Results

Monomers (Mole Ratio in Feed)	Method (Solvent)*	Reaction Temperature °C	Reaction Time hr	Monomer** %	AIBN† %	Results
1a + 13 (80) (20)	Solution (Benzene)	75	0.08	25	0.025	Cross-linked gel
2a + 13 (80) (20)	Solution (Benzene)	75	0.25	25	0.010	63 percent yield
2a + 31 (95) (5)	Solution (2-Butanone)	78	3.00	25	0.013	Quantity yield
2a + 31 (90) (10)	Solution (2-Butanone)	78	3.00	25	0.013	88 percent yield
2a + 31 (80) (20)	Solution (2-Butanone)	78	3.00	25	0.013	81 percent yield
1a + 33 (80) (20)	Solution (Benzene)	60	38.00	25	0.050	46 percent yield
2a + 9 (80) (20)	Bulk	72	4.00	--	0.050	49 percent yield
2a + 9 (50) (50)	Bulk	76	3.00	--	0.050	60 percent yield
1a + 31 (80) (20)	Solution (Benzene)	60	1.00	25	0.010	Low yield

* Where applicable.

** Weight-to-volume percent where applicable.

† Azobisisobutyronitrile; concentration weight-to-volume percent for solution method and weight-to-weight percent for bulk method.

Vinyl 2,3,6-trichlorophenylacetate (14) was copolymerized with 13 using a mole ratio of 14:13 of 90:10. The bulk-free-radical polymerizations gave a large amount of cross-linked material and a low yield (<10 percent) of chloroform-soluble polymer.

The solution-free-radical copolymerization of 2-acryloyloxyethyl 2,4-dichlorophenoxyacetate (2a) with methacrylic acid (31) was carried out using mole ratios of 2a:31 of 95:5, 90:10, and 80:20. The copolymers 32a, 32b, and 32c, which were obtained in greater than 80 percent yields, are soluble in chlorinated hydrocarbons, acetone, and 2-butanone. The copolymers have inherent viscosities of 0.26, 0.14, and 0.38 dl/g, respectively. Infrared and elemental analyses of 32c indicate that the copolymer contains 20 percent methacrylic acid. Elemental analyses of 32a and 32b were not obtained due to the fact that the calculated values are nearly identical to those expected for the homopolymer of 2a and, therefore, are of little analytical value.

The solution-free-radical copolymerization of vinyl 2,4-dichlorophenoxyacetate (1a) and N-vinyl-2-pyrrolidone (33) with a feed mole ratio of 1a:33 of 80:20 afforded the copolymer 34. The copolymer is soluble in chlorinated hydrocarbons and hot benzene and has an inherent viscosity of 0.20 dl/g. Infrared and elemental analyses indicate that the polymer contains 30 percent 1a.

Table 3
Physical and Spectral Data for 2,4-Dichlorophenoxyacetate Copolymers

Copolymer	ir (cm^{-1})	η* (Solvent)	Elemental Analysis** C	H	Cl	N
29	1730 (C = 0) 2990 (COOH)	0.70 (TCE)†	48.98 48.68	3.88 3.95	21.03 21.03	
32a	1730 (C = 0)	0.26 (MEK)††				
32b	1730 (C = 0) 3000 (COOH)	0.14 (MEK)				
32c	1740 (C = 0) 3020 (COOH)	0.38 (MEK)	49.36 49.42	3.99 4.11	20.81 20.81	
34	1750 (C = 0)	0.20 (BzCl)‡	51.23 50.87	4.05 4.14	24.06 24.04	2.04 2.12
35a	1750 (C = 0) 1580 (N - H)	0.44 (BzCl)	49.95 49.82	4.40 4.59	19.99 19.45	1.97 2.54
35b	1750 (C = 0) 1580 (N - H)	0.20 (BzCl)	50.89 50.48	4.97 4.98	17.91 17.75	3.81 3.62
1a + 31	1720 (C = 0) 3000 (COOH)					

* Inherent viscosity (dl/g) at 30° and 0.5 g/dl.
** Calcd/Found.
† Sym-tetrachloroethane.
†† 2-butanone.
‡ Chlorobenzene.

Two bulk-free-radical copolymerizations of 2a and trimethylamine methacrylimide (9) using mole ratios of 2a:9 of 80:20 and 50:50 were carried out to afford the copolymers 35a and 35b in 49 and 60 percent yields, respectively. The copolymers are soluble in chlorinated hydrocarbons and acetone and have inherent viscosities of 0.44 and 0.20 dl/g, respectively. Infrared and elemental analyses indicate that 35a contains 25 percent 9 and 35b contains 35 percent 9.

Hydrolysis of Copolymers at pH 8

A study of the release rates of the 95:5, 90:10, and 80:20 copolymers of 2-acryloyloxyethyl 2,4-dichlorophenoxyacetate and methacrylic acid (32a-c) at pH 8.08 was carried out. The polymers were immersed in a boric acid-sodium hydroxide buffer solution at 30°C, and the amount of herbicide released was determined periodically by spectrophotometric analysis. The copolymer 32c containing 20 percent methacrylic acid released 117 mg of 2,4-D in the first 6 days of the study. This rapid hydrolysis was accompanied by considerable swelling of the polymer particles, which prevented further spectroscopic analysis of the sample solutions. The copolymer 32a containing 5 percent of the hydrophilic acid residue released 13.0 mg of herbicide in 78 days, while the copolymer 32b containing 10 percent acid released 28.7 mg of 2,4-D in 76 days. These accelerated release rates are in sharp contrast to

that of poly(2-acryloyloxyethyl 2,4-dichlorophenoxyacetate), which released less than 0.9 mg of 2,4-D in 206 days under the same conditions (Figure 8).

A study of the release rates of the 70:30 copolymer of vinyl 2,4-dichlorophenoxyacetate and N-vinyl-2-pyrrolidone (34) at pH 8.08 was also carried out. The data shown in Figure 9 were obtained by employing the procedure described above. The copolymer released 3.3 mg of 2,4-D in 118 days. (The homopolymer, poly(vinyl 2,4-dichlorophenoxyacetate), released approximately 1.4 mg of herbicide in 154 days.)

The results of a study of the hydrolysis of the 75:25 and 65:35 copolymers of 2-acryloyloxyethyl 2,4-dichlorophenoxyacetate and trimethylamine methacrylimide at pH 8.08 are shown in Figure 10. The copolymer 35a containing 25 percent of the hydrophilic aminimide residue released 5.1 mg of herbicide in 207 days. The rate of hydrolysis of this copolymer is not significantly different than that observed for the copolymer containing 13 percent 9. However, the copolymer 35b containing 35 percent of the aminimide release 133.4 mg of 2,4-D in 123 days.

Preparation of Samples for Preliminary Field Evaluation

The syntheses of copolymers 32a, 32b, and 35b were scaled up to provide 10-g samples for evaluation in 8-*l* containers. An additional 770 g of copolymer 32b were prepared for field testing in pools.

Fenac acid was also physically incorporated in a polyethylene matrix. The formulation, which contained 20 percent fenac acid, 8 percent ferrous oxide, and 72 percent high-density polyethylene, was prepared in the form of 0.5-g pellets. Approximately 900 g (1800 pellets) were sent along with the above samples to the University of Southwestern Louisiana for evaluation.

CONCLUSIONS AND RECOMMENDATIONS

Vinyl monomers containing fenac can be prepared in reasonable yields. These monomers can be polymerized by free-radical techniques to afford the corresponding polymers. The polymers' viscosities are not as high as those of polymers prepared from vinyl monomers containing 2,4-D.

Homopolymers containing 2,4-D or fenac as pendent substituents will not undergo hydrolysis in water with a pH of 7 or 8 at 30°C. Increasing the length of the pendent side chains does not result in the hydrolysis of the herbicide-polymer ester bonds.

Copolymers containing 2,4-D or fenac and hydrophilic residues will slowly hydrolyze in water at 30°C. Increasing the pH from 7 to 8 does not significantly enhance the rate of hydrolysis. The rate is dependent on the amount and type of the hydrophilic group used. Carboxylic acid groups serve as the most effective intramolecular catalyst for the hydrolysis.

Future research should be directed towards the development and evaluation of copolymers containing herbicides and hydrophilic residues, since they appear to have considerable potential as controlled-release agents. The results of this study indicate that copolymers can be prepared with release rates that vary from several weeks to several years.

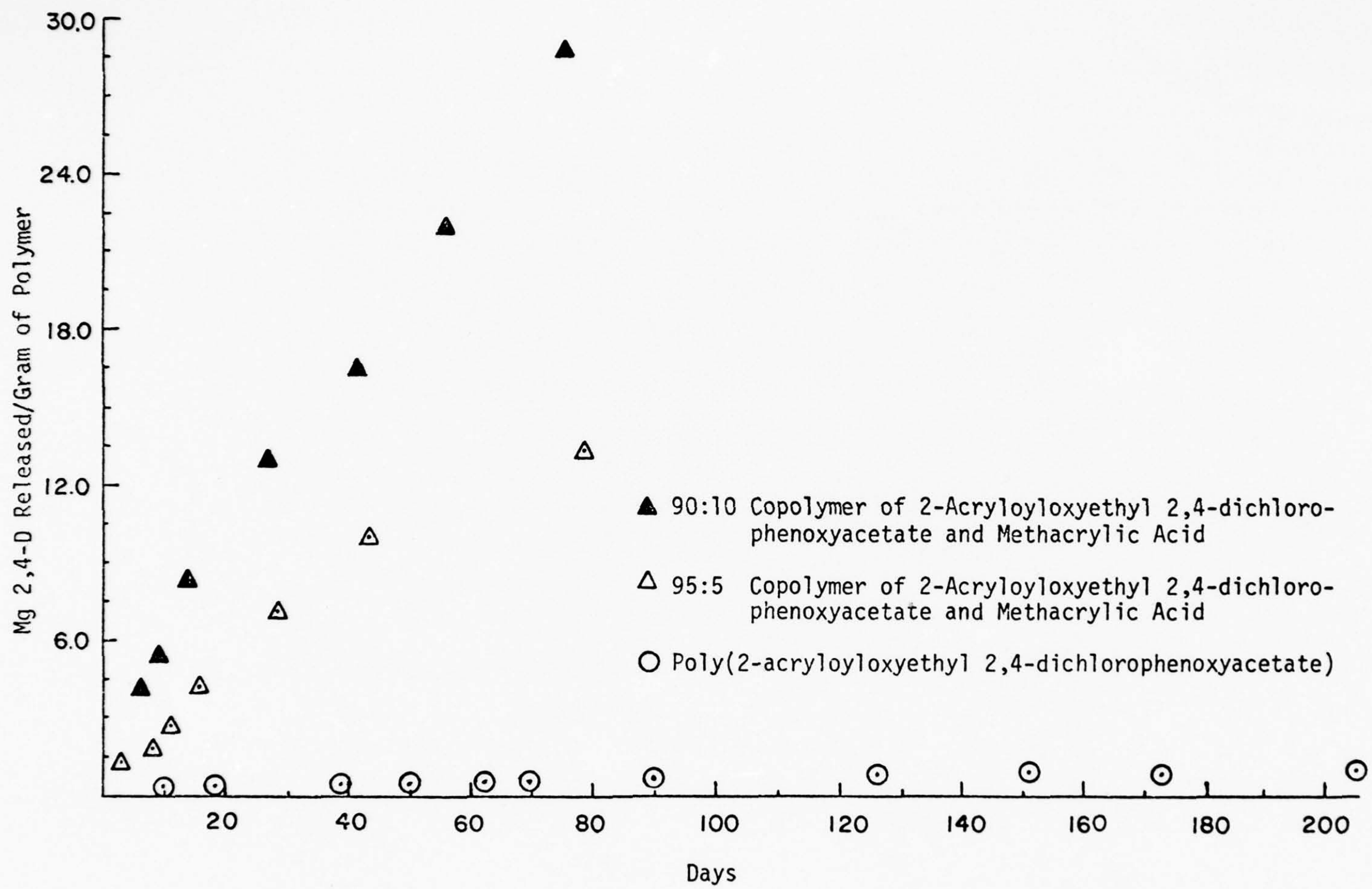

Figure 8. Hydrolysis of methacrylic acid copolymers

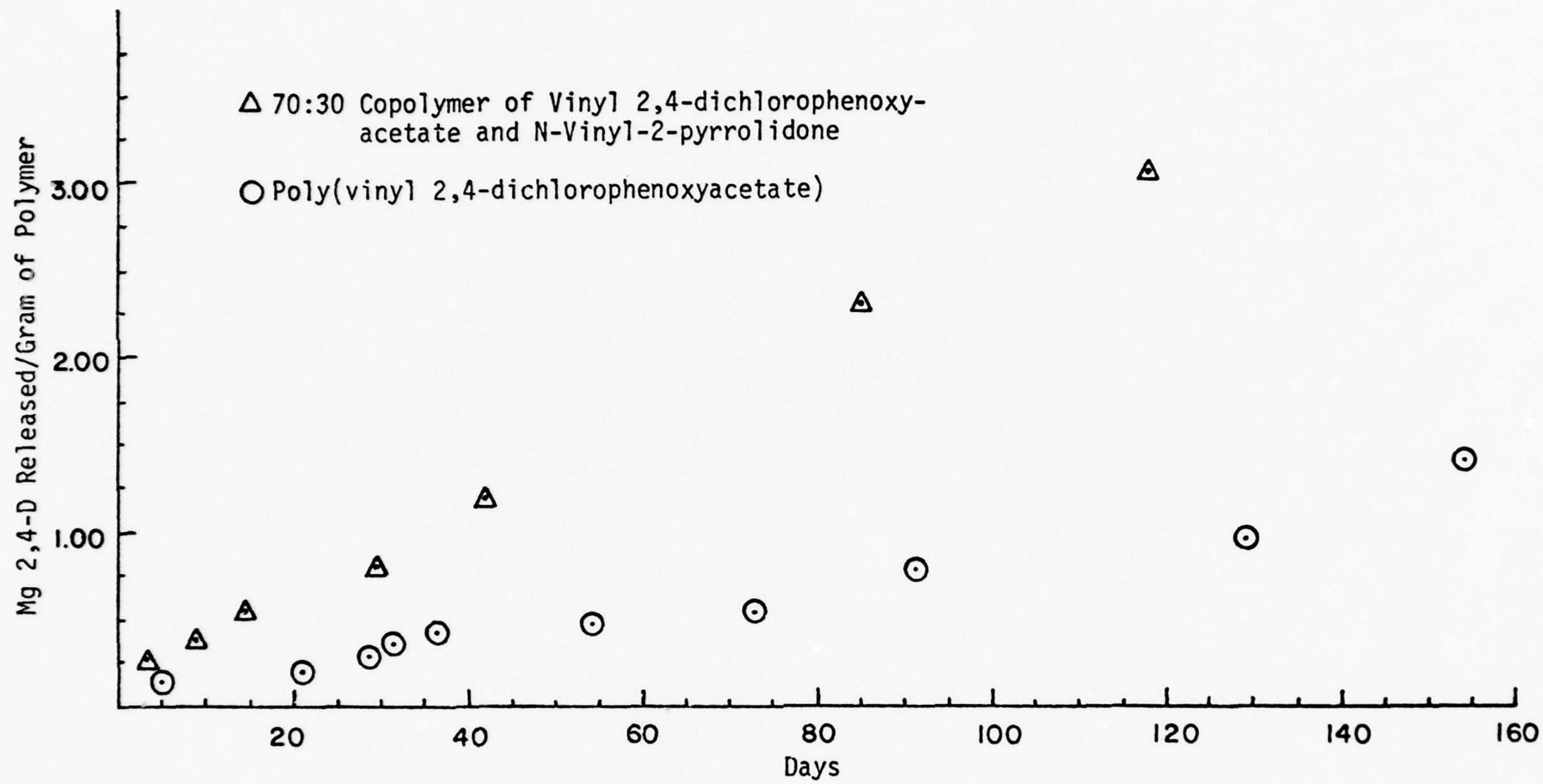

Figure 9. Hydrolysis of N-vinyl-2-pyrrolidone copolymers

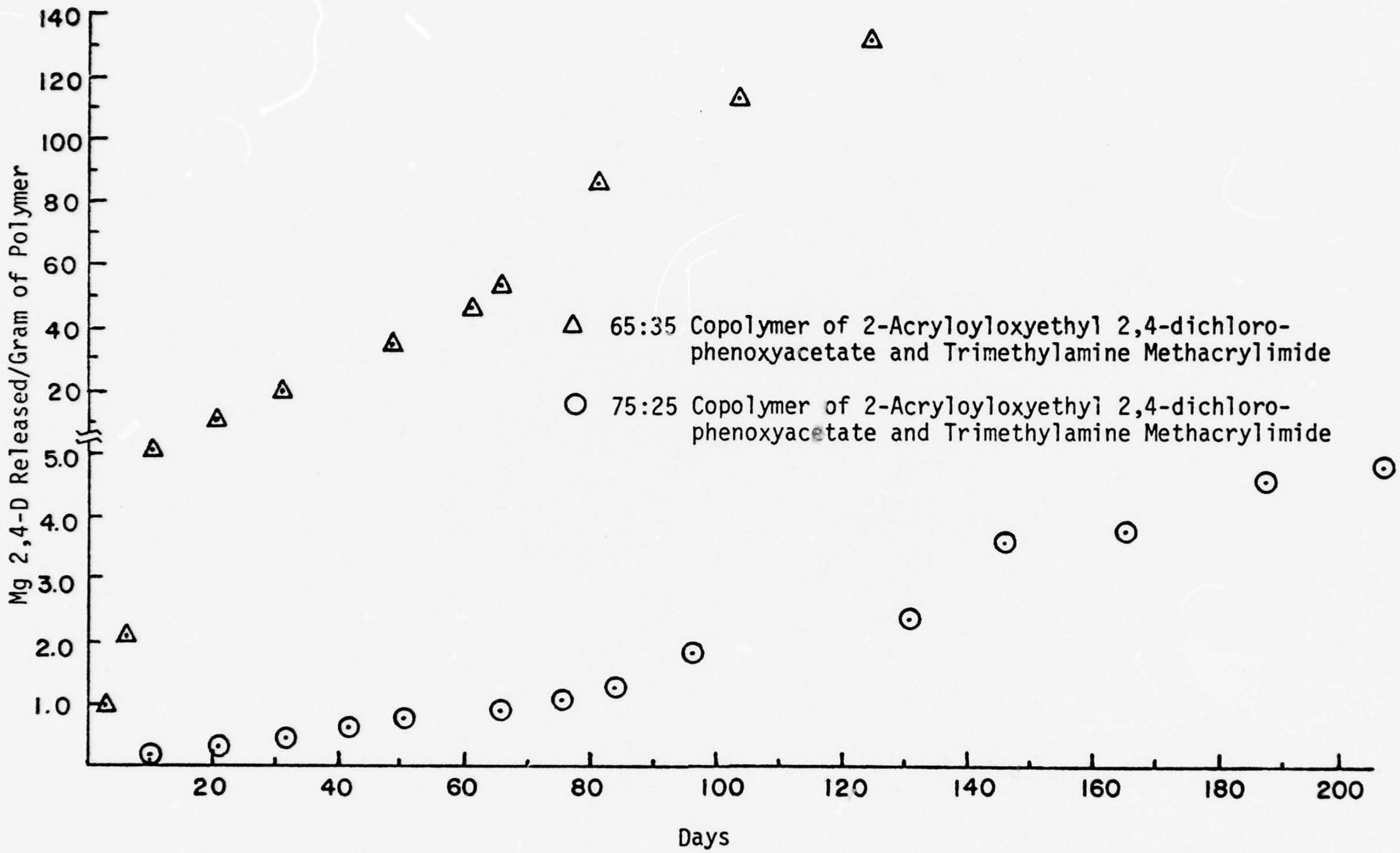

Figure 10. Hydrolysis of trimethylamine methacrylimide copolymers

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DEVELOPMENT AND EVALUATION OF CONTROLLED RELEASE HERBICIDES

by

G. A. Janes*

INTRODUCTION

The research in this study is designed to establish effective dosages of controlled release Diquat, 2,4-D acid, Silvex, Fenac acid, Fenuron, and Endothall. Formulations of these phytotoxic agents were prepared at 100, 90, 50, 25 percent of their respective maximum loadings in various elastomeric bases. The initial loss rate analyses indicate the toxicants are releasing and will be usable CR systems.

BACKGROUND

In the past we have shown that the butoxyethanol ester of 2,4-D could be released effectively from elastomeric compounds. Various pool and small field tests followed, with the materials produced as floaters, suspenders, and sinkers to allow for the selective treatment of the pertinent phytozone.

Discovery of the surprising efficacy of very small dosages in these studies led to the investigation of chronic intoxication of aquatic weeds and recognition of the "Chronicity Phenomenon."

Fourteen herbicidal materials were examined against eight major water weeds and the chronicity phenomenon was found in most, though not all, instances.

Silvex, Diquat, and 2,4-D acid showed ability to destroy aquatic weeds at 0.01 ppm/day to 0.001 ppm/day; these were subsequently developed into study compounds. The compounds were placed in bioassay, and the results were favorable.

FORMULATIONS

Six controlled release master-batch formulations, including two of the ones previously found effective, were selected. Portions of the master batch were turned on the rubber mill, and the given herbicide was slowly added to the point where no more was acceptable by the formulation. This was established as the "maximum" loading. In the subsequent millings each master-herbicide combination was reduced to the selected study levels.

The elastomers used were hot polymerized styrene-butadiene copolymer, cold polymerized styrene-butadiene copolymer, natural rubber, synthetic natural rubber, cis polybutadiene, and an ethylene-propylenediene terpolymer. The master-batch formuations are shown in Table 1 and Table 2 shows the maximum loadings found in this compounding study.

The processibility varies with each formulation. 2,4-D acid presents no problem. Silvex is difficult and tacky at the maximum loading levels, especially with the synthetic natural rubber base. The dust from Diquat constitutes a hazard to the operator and would require positive over-mill ventilation. Fenuron melts out and a probable loss of 10 to 20 percent is apparent. Fenuron also produces vapors

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Table 1
Master Recipes

Ingredients	A-1001	A-4616	CB-220	SN-600	NRX	EPCAR
Ameripol 1001	100.00	--	--	--	--	--
Ameripol 4616	--	100.0	--	--	--	--
Ameripol CB	--	--	100.0	--	--	--
Synthetic NR	--	--	--	100.0	--	--
Natural rubber	--	--	--	--	100.0	--
EPCAR 5465	--	--	--	--	--	100.00
ISAF black	15.00	15.0	--	--	--	--
HAF black	--	--	15.0	15.0	15.0	--
SRF black	--	--	--	--	--	10.00
Zinc oxide	3.00	3.0	3.0	3.0	3.0	3.00
Sulfur	2.00	2.0	1.4	2.0	--	1.25
Altex	1.75	2.5	--	--	--	--
Stearic acid	--	1.5	2.0	0.5	0.5	0.50
NOBS 1	--	--	1.2	--	--	--
CBTS	--	--	--	2.0	2.0	--
TMTDS	--	--	--	--	1.0	1.00
Captax	--	--	--	--	--	0.75
Sulfads	--	--	--	--	--	0.75

Table 2
Maximum Mill Loading (Percent) of Selected Agents

	Base Recipe					
Agent	A-1001	A-4616	CB-220	SN-600	NRX	EPCAR
2,4-D acid	37.0	80.0	82.1	57.2	61.2	53.2
Diquat	54.3	68.6	64.4	55.5	65.8	73.0
Silvex	80.2	75.2	66.0	47.4	48.4	49.6
Fenac acid	33.0	66.8	52.2	57.6	44.4	68.0
Endothall	49.1	47.0	54.7	73.0	45.8	50.0
Fenuron	53.9	57.6	51.2	50.0	57.2	68.5

that affect the mucous membranes. Endothall produces heavy vapors and would require positive ventilation, as well as tight-fitting safety goggles for the operator.

LOSS RATE ANALYSIS

A spectrophotometric standard curve was determined for 2,4-D acid, Diquat, and Silvex. These curves are used to establish the loss rate of the agents from each of the polymer bases at the various loading levels. Loss rates are measured at both 70° F and 80° F to determine the effect of temperature on the release rates.

Table 3 shows the release rate of 2,4-D acid at 70° F from the hot and cold polymerized Styrene-butadiene and the cis polybutadiene formulations. In each case the formulations show significant CR efficacy. By contrast, some of the early data for Diquat show excessively high release; consequently, further refinement in technique is indicated.

Of particular interest is the release of essentially all of the 2,4-D from the highest loading CB rubber in 100 days. A pattern of this type is often needed to minimize residual active agent. By working with pellet size, the ppm/water of the herbicide could be reduced to essentially zero after 4 months of control activity if this release rate holds up in further testing.

Table 3
2,4-D Acid Loss Percent Analysis at Various 2,4-D Acid Loading Levels
70° F DM Water*

Time	A-4616			A-1001			CB-220	
Days	72.0%	40.0%	20.0%	33.3%	18.5%	9.3%	73.9%	41.1%
1	3.7	6.0	3.4	6.2	3.8	9.5	3.2	6.1
2	6.5	9.0	5.0	8.5	5.2	11.7	7.2	11.5
4-7	10.6	16.5	9.3	14.0	8.4	13.7	16.6	18.9
9-14	14.2	23.1	13.6	18.9	11.3	17.5	25.6	25.1
15-21	16.9	26.8	15.7	21.5	13.0	19.3	33.3	30.3
22-28	19.5	30.0	17.7	24.0	14.5	21.1	41.8	34.7
29-35	21.7	32.4	19.2	26.1	15.8	22.7	50.1	38.2
36-42	24.2	35.2	21.4	28.4	17.3	24.4	55.4	41.3
43-49	26.5	37.5	22.9	30.2	18.6	25.7	61.6	44.3
50-56	28.5	39.4	24.1	31.6	19.6	27.0	66.8	41.5
57-63	30.4	41.4	25.3	33.1	20.7	28.1	70.8	48.4
64-70	32.2	42.9	26.2	34.2	21.6	29.0	75.6	50.4
71-77	33.5	44.1	26.9	35.1	22.4	29.7	79.6	52.4
78-84	35.2	45.7	27.8	36.2	23.3	30.3	83.4	54.2
85-91	36.9	47.7	28.7	37.2	24.1	30.9	86.7	56.2
92-98	38.8	49.4	29.6	38.3	25.0	31.5	89.0	57.9
99-105	40.6	51.0	30.5	39.3	25.8	31.9	90.8	59.7

* Accumulative percent loss (time in days).

BIOASSAY

Controlled release herbicide dosages necessary for 30-day plant mortality can be determined by coupling the earlier chronicity study* with the now known loss rate for the current formulations. Where loss rates are not available, bioassay *evaluations are performed at 10 ppm a.*

Tests are conducted on replicates of three plants in 1-gal aquaria containing 3 *l* water and 100 gm standardized soil. Gro-lux lighting is used on a 14-hr day, 10-hr night cycle. Plants are conditioned from 5 to 7 weeks before the poisoning regime is started. Observations are made for 30 days or until 100 percent mortality.

To date evaluations against Cabomba and milfoil have shown effective CR control in a 30-day period by Fenac and Endothall compounds.

SUMMARY

The combination compounding, loss rate analysis, and bioassay study is aimed at establishing effective treatment levels for CR Diquat, 2,4-D acid, Fenuron, and Endothall as well as Silvex and Fenac acid. Model control release formulations are developed and tested.

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* U. S. Army Corps of Engineers contract DACW73-72-C-0031, "Chronicity Study."

EFFICACY EVALUATION OF CONTROLLED-RELEASE HERBICIDES

by

J. R. Barry*

For controlled-release herbicides to join the arsenal of operational tools that may be used for combatting aquatic weed pests, several criteria must be met. The chemical or chemicals along with the delivery systems must first be safe to man and in harmony with the environment to gain Environmental Protection Agency approval for use. The formulations must meet certain economic standards in order that they might be used practically in aquatic situations. In addition, controlled-release formulations must be effective in controlling problem aquatic plants.

The present contract between the Corps of Engineers and the University of Southwestern Louisiana involves efficacy studies with controlled-release aquatic herbicides. This report summarizes the work conducted at the University with controlled-release herbicides through October 20, 1976. At this point only preliminary data are available, and final conclusions must be delayed until the experiment is completed.

CONTROLLED-RELEASE FORMULATIONS

The following formulations were tested in this experiment:

a. CBL#E51, a rubber-copper sulfate monohydrate combination containing 17.5 percent CU^{++} with a release life of 5 to 7 months.

b. CBL#14ACE-B, a rubber-2,4-D combination containing 18.7 percent, 2,4-D BEE with a release life of 2 years.

c. Fenac Wafer, a polyethylene-Fenac formulation containing 20 percent Fenac acid, 70 percent polyethylene, and 8 percent iron oxide.

The CBL#E51 and CBL#14ACE-B formulations were provided by George Janes of Creative Biology Laboratory at Barberton, Ohio, and the Fenac-polyethylene formulations were obtained from Frank Harris of Wright State University of Dayton, Ohio.

EXPERIMENTAL DETAILS

The aquatic species included in this study were waterhyacinth (*Eichhornia crassipes* (mart.) Solms—Laubach), hydrilla (*Hydrilla verticillata* Royle), egeria (*Egeria densa* Planchon), Eurasian watermilfoil (*Myriophyllum spicatum* L.) and coontail (*Ceratophyllum demersum* L.). These species were chosen because they are particularly troublesome in Louisiana and throughout many other regions of the South. The four submersed species were established in individual flats containing a medium consisting of one-half silt loam soil and one-half coarse sand. Duplicate flats of each species were placed into the experimental pools, and a dozen healthy waterhyacinth plants were floated on the pool surfaces.

The experimental pools were formed by excavation and construction of earthern levees. The pools were approximately 3 m square and 1/2 m deep and were lined with 6-mil black polyethylene film. The pools were filled to a depth of 0.3 m with tap water, and the appropriate plant species were placed into

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each pool on July 12 and 13. Each pool comprised an experimental plot containing duplicate flats of the four submersed aquatic species and 12 floating waterhyacinth plants. Triplicate plots (pools) were treated with the 9 treatments listed in Table 1. A total of 27 pools was used for this experiment. The herbicide treatments were applied to the pools on July 29, 1976.

Visual ratings of weed control were recorded on August 18, September 19, and October 19, 1976. Ratings were based upon a scale of 0 to 10, where 0 represented the most vigorous and healthy of the plant colonies and 10 represented complete kill of the weed colony. Both flats of each species were rated for each pool, and the average of the two ratings was recorded. Results of the first two ratings are shown in Table 1; however, time did not permit inclusion of the October 19 ratings in this report.

Table 1
Evaluations of Controlled-Release Herbicides in Outdoor Pools, 1976*

	Hydrilla		Egeria		Hyacinth		Coontail		Milfoil	
Treatment**	8/25	9/19	8/25	9/19	8/25	9/19	8/25	9/19	8/25	9/19
Nontreated check	2.67	0.33	5.83	3.67	2.00	1.33	4.00	0.67	0.33	0.67
14 ACE-B at 10 ppm (rubber-2,4-D BEE)	2.00	1.67	3.67	3.67	1.33	2.67	2.25	4.33	5.75	10.00
14 ACE-B at 20 ppm (rubber-2,4-D BEE)	2.17	1.00	5.83	3.67	4.17	4.00	3.50	4.33	6.83	4.67
14 ACE-B at 40 ppm (rubber-2,4-D BEE)	2.67	3.67	4.67	5.33	5.67	7.00	4.17	6.00	6.17	9.00
E51 at 25 ppm (rubber-CuSO)	1.83	5.33	4.07	7.33	4.67	8.00	7.50	9.33	4.33	5.33
E51 at 50 ppm (rubber-CuSO)	4.33	5.33	6.50	7.67	6.17	7.67	5.83	9.67	6.67	5.00
E51 at 100 ppm (rubber- CuSO)	5.50	4.67	7.83	7.00	7.33	8.67	8.83	8.33	6.17	5.67
Fenac wafer at 30 ppm (polyethylene-Fenac)	1.83	2.33	4.50	5.33	3.00	5.33	4.67	7.33	5.67	10.00
Fenac wafer at 60 ppm (polyethylene-Fenac)	3.67	4.33	6.67	6.67	5.83	8.67	5.83	8.67	7.00	10.00

* Ratings based upon a scale of 0-10 where 0 = maximum vigor and 10 = complete weed kill.
** Treatment rates are based upon weight of formulation.

RESULTS AND CONCLUSION

The September 19 ratings show the rubber—2,4-D BEE formulation was most active on Eurasian watermilfoil with moderate herbicidal activity showing in the coontail and waterhyacinth colonies. Observations of plots made on October 19 showed complete kill of all the Eurasian watermilfoil colonies at all applied rates and substantial damage to coontail and waterhyacinth colonies at the 40-ppm rate. Egeria and hydrilla were not adversely affected by the rubber—2,4-D formulation at the October 19 observation.

The rubber-copper sulfate formulation showed the greatest herbicidal activity in colonies of coontail, waterhyacinth, and egeria on the September 19 rating. On the October 19 observation, coontail was essentially eradicated and phytotoxicity in the waterhyacinth, egeria, and hydrilla colonies had increased substantially. All species were sensitive to the rubber-copper sulfate formulation at the rates tested.

In the pools treated with the polyethylene-Fenac formulation, Eurasian watermilfoil was eradicated from the test pools by the September 19 rating. Coontail, waterhyacinth, and egeria also showed moderate to high sensitivity to this treatment. On the October 19 observation, coontail had been eradicated from pools at both the 30- and 60-ppm rates, and waterhyacinths and egeria were eradicated at the 60-ppm rate. Hydrilla at this point showed only a moderate sensitivity to the polyethylene-Fenac formulation.

The high levels of herbicidal activity noted both on the September 19 and October 19 observations indicate that rates tested are above those needed to achieve the "chronicity phenomenon" described by Janes.* Analysis of water samples for herbicide residue levels will indicate the herbicide exposure levels at various time stages through the course of this study.

When all the data have been collected and analyzed, the results will serve as a basis for a more detailed study during the 1977 season. Emphasis of future work will be placed upon rate refinements of the formulations tested and evaluation of other controlled-release formulations.

* Janes, George A., "Chronicity Phenomenon," *Controlled Release Pesticide Symposium*, University of Akron, Akron, Ohio, 1974, pp 14.1-14.13.

PROGRESS IN THE USE OF PLANT PATHOGENS AS BIOLOGICAL CONTROLS FOR AQUATIC WEEDS

by

R. Charudattan, T. E. Freeman, and K. E. Conway*

INTRODUCTION

Our research efforts have been focused mainly on *Eichhornia crassipes* (Mart.) Solms and *Hydrilla verticillata* Royle. Much of our experimental and field successes have been with waterhyacinth. Currently, we are in a position to recommend the experimental field use of two fungal pathogens, *Cercospora rodmanii* Conway and *Acremonium zonatum* (Saw.) Gams against waterhyacinth. These fungi have proven effective when tested alone or in combination with available insect biocontrols. We believe that we have set the stage for the entry of these two native pathogens into the waterhyacinth control scene. We suggest that the agencies concerned with aquatic weed control must incorporate plant pathogens in their control strategies. We are continuing our search for more pathogens of aquatic weeds and better use of existing ones. This report also includes summaries of our research findings on a highly specific, obligate rust pathogen of waterhyacinth, *Uredo eichhorniae* Fragoso and Ciferri, our experiments on integrating pathogens and insects to control waterhyacinth, and pathogens of hydrilla.

WATERHYACINTH

Cercospora rodmanii

Last year Dr. Conway reported on this pathogen and on the overall success with this candidate biocontrol agent. Since his last report, Dr. Conway has gathered more field data from Fish Prairie, near Micanopy, Florida, which have confirmed his earlier observations on (a) the patterns of infection cycles and spread of *C. rodmanii*, (b) the type of host damage, and (c) the effect of *C. rodmanii* on the decline of waterhyacinth. Encouraged by Conway's results,[1,2,3] we are currently negotiating with Abbott Labs, North Chicago, Illinois, for experimental mass-production of *C. rodmanii* inoculum for field trials in early 1977.

Acremonium zonatum

Highly encouraging and significant results have been obtained in our studies on integrated biocontrol using *A. zonatum* and *Neochetina eichhorniae* and *Orthogalumna terebrantis*. A survey of the fungal and bacterial flora of waterhyacinth infested with the two arthropods, *N. eichhorniae* (weevil) and *O. terebrantis* (mite), was undertaken to determine the role of microorganisms in the decline of this host in Florida waters. In several sites near Fort Lauderdale, arthropod-damaged plants have been observed to come under severe attacks by parasitic microorganisms, including *A. zonatum* which appears to be most destructive in south Florida. Symptoms of pathogenic infections on these plants were leaf necrosis, zonate ring spots, lesions, and water-soaking, especially on laminae and petioles damaged

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by larvae of the weevil and on laminae damage by the mite. Occasionally, root-rotting was also seen, but specific pathogens were not isolated.

Several plant diseases are transmitted by insects by their movement and/or feeding on plants. Specifically, this study was aimed at finding: (a) role of pathogens in decline of arthropod-infested waterhyacinths in Florida; (b) types of pathogens involved; (c) relationship between arthropods and pathogens, whether the relationship is direct, involving active transmission of any pathogen, indirect due to secondary invasion of damaged plants by pathogens, or unrelated, involving independent occurrence of the pathogens; and (d) potential for use of an arthropod-pathogen combination to control waterhyacinth.

Several parasitic fungi, including some known pathogens of waterhyacinth, and soft-rot bacteria were isolated from arthropod-infested and noninfested plants. Higher numbers of microorganisms were present on arthropod-infested plants than on noninfested plants. However, fungi and bacteria occurred randomly on arthropod-damaged waterhyacinth. *A. zonatum* was isolated consistently from arthropod-damaged plants. Significant association between *O. terebrantis* (mite) and *A. zonatum* was borne out by statistical analysis, which could be corroborated with field observations. Significant reduction in plant dimensions and in numbers of live leaves per plant resulted from the combined attacks of arthropods and pathogens. Correspondingly, significant increase in the numbers of dead leaves per arthropod infested-diseased plant was observed, proving the capacity of these biotic agents in causing waterhyacinths to decline.

Transmission of fungi and bacteria by the arthropods. In laboratory tests arthropods were not selective of any fungus or bacterium and no vector relationship was evident. Surface-sterilized, crushed weevils and nonsurface-sterilized mites yielded several fungal colonies on potato dextrose agar medium. However, only species of *Cladosporium* and *Phoma* proved mildly pathogenic to waterhyacinth in our tests. *Acremonium zonatum* or *C. rodmanii* were not isolated from these arthropods sampled. None of the bacteria isolated were pathogenic to waterhyacinth; but combined suspensions of these bacteria were capable of soft-rotting potato disc, which indicated their general ability to rot plant tissues. It is likely that some of these bacteria invade and rot the arthropod-infested waterhyacinths under field conditions. Plantings of weevil feces yielded several hundred fungi and bacteria among which no dominant fungal or bacterial types were observed, indicating the absence of a specific relationship between the weevil and any microorganism. None of these microorganisms from weevil feces were pathogenic to waterhyacinth.

Synergistic effects of "A. zonatum" *and the weevil:* The effect of spraying *A. zonatum* on waterhyacinths that had been previously fed upon by weevils was evaluated in the greenhouse to study if this combination would be more effective in killing waterhyacinth than either of the agents alone. The following five treatments were set up, each with twelve washed waterhyacinths: (a) weevils plus *A. zonatum*; (b) weevils alone; (c) *A. zonatum* alone; (d) control, treated with 0.7 percent Malathion and 0.5 percent Benlate; and (e) untreated. Treatments (a) and (b) received 40-48 weevils per treatment (3.3 to 4.0 weevils per plant). Plants in (c) were untreated, while plants in treatment (d) were dipped in Malathion. Nine days after arthropod infestation, treatments (a) and (c) were sprayed with *A. zonatum* and treatment (b) was sprayed with sterile water. Treatment (d) was sprayed with Benlate. Results were recorded over a period of 52 days.

Plants with *A. zonatum* (treatments (a) and (c)) developed characteristic symptoms of disease within a week after spraying. The degree of infection was higher in treatment (a). The insect damage was equally severe in treatments (a) and (b). By the 32nd day, the weevil damage was so severe that fresh, healthy waterhyacinth had to be added to treatments (a) and (b), as food for the weevils. By the 52nd

day, all the original plants had died in treatment (a) with no sign of regrowth. Plants in treatment (b) were severely damaged by the weevils, but alive, and in (c), moderately infected and alive. Control plants had no *A. zonatum* infections and were alive. This study proved the potential effectiveness of the weevil-*A. zonatum* combination in the control of waterhyacinth. It was evident that the synergistic effects of *A. zonatum* and weevil were more stressing on waterhyacinth that the effect of either agent alone.

Field observations and our experimental evidence confirmed that *A. zonatum* and other microorganisms played a significant role in the decline of arthropod-infested waterhyacinths in our sample sites. Even though the rates of microbial attacks were greater in arthropod-damaged plants, there was a lack of direct relationship between arthropods and the presence of specific fungi and bacteria isolated. Around Fort Lauderdale where this study was done, *A. zonatum* is ubiquitous. In our tests, the arthropods did not seem necessary for incidence of pathogens. However, they created ports of entry for pathogens, especially for *A. zonatum*, thereby aiding pathogenic attacks. Due to the widespread occurrence of *A. zonatum* on arthropod-infested waterhyacinths, and the lack of positive data, we could not prove or rule out transmission of this or other pathogens by the arthropods. Considering the above findings, we recommend that a combination of pathogens and arthropods be tried as an integrated biological control system in south Florida. The process of pathogen-arthropod interaction occurs naturally but is subject to the effects of varying climatic conditions. Hence, it is necessary to time any fungus application or arthropod manipulation to enhance the interaction. Selecting and increasing incidence of virulent pathogens through induced ephiphytotics may hasten this process with definite results. *Acremonium zonatum* would seem one of the ideal candidates for integrated biocontrol for the following reasons: (a) It is a frequent foliar pathogen of waterhyacinth in Florida and the southeastern United States. (b) It has a limited host range.[4] (c) Its spores are bound in a slimy matrix and would be ideal for dispersal by arthropods.

The combination of *A. zonatum* and arthropods should be more effective when used with natural infestations of the waterhyacinth mite. We are currently field testing this combination in Florida. In the past, the roles of pathogens in control of insect-infested weeds have been overlooked or largely underrated. The significance of pathogens in augmenting the effects of the waterhyacinth weevil and the mite has been evident from this study. As a logical step, the use of other pathogens and insects of waterhyacinth in combinations should be attempted for integrated biological control of waterhyacinth. A publication based on this research has been prepared and will soon be submitted to Weed Science.[5]

Waterhyacinth Rust

Uredo eichhorniae Fragoso and Ciferri, causal agent of a rust disease on waterhyacinth, is one of the newer pathogens that we have begun studying. This rust has been found in its uredosporic stage in several locations in Argentina, Uruguay, and southeastern Brazil, but not in the United States or the Eastern Hemisphere.[6,7]

Symptoms, host damage, and seasonal occurrence of "U. eichhorniae." Rust-infected waterhyacinths are conspicuous in the field. Pronounced yellowing of leaves along with typical "rusting" are characteristic symptoms incited by this pathogen. Extensive host damage due to *U. eichhorniae* has been observed in some locations in Argentina. The occurrence of *U. eichhorniae* in Argentina from July 1975 to June 1976 was monitored monthly at two locations, at Campana (ca 60 km northwest of Buenos Aires) and at Arroyo Baltazar in Entre Rios province (ca 50 km north of Campana). The former, a lagoon off Rio Parana is approximately 2 ha in area, while the latter, a wayside overflow from a rivulet, is about 200 m^2. At both sites the waterhyacinth populations have persisted for a number of years.

During the observational period no spermatia, aecia, or telia developed on waterhyacinth at these sites. The rust was found in its uredial stage throughout the year in Campana and from July through October (winter) and April through June (fall) at Arroyo Baltazar.

Relation of rust incidence to climatic conditions. Temperature, relative humidity, and precipitation data for 1975-76 from a weather station of the Fuerza Aerea Argentina, ca 70 km from the survey sites, were compared with rust incidence. The incidence of *U. eichhorniae* was expressed in terms of number of rust pustules on infected leaves, averaged from at least 100 leaves. At both sites combined, higher incidences of the rust were seen in July and December of 1975 and in April, May, and June of 1976. During these months the mean temperatures were 30.0°C (day) and 3.1°C (night) with absolute temperatures of 36.4°C (day) and -4.0°C (night). The highest rust incidence was recorded in May 1976 for both sites at mean temperatures of 19.5°C (day) and 6.5°C (night) and absolute temperatures of 25.5°C (max) and -0.6°C (min). The rust incidence was low or absent in summer even though the mean and absolute temperature maxima were lower than those recorded in December (late spring).

Relative humidity (RH) in 1975-76 ranged from 68 to 88 percent (24-hr monthly averages) for these sample sites; January or the beginning of summer having had the lowest RH. The combination of lower RH and higher mean temperatures in December and January (70 and 68 percent RH and 30.0° and 28.2°C temperatures, respectively) seemed unfavorable for the rust. No definite relation between higher levels of precipitation and rust incidence was evident even though higher precipitation levels may be expected to favor the rust through an increase in RH.

The fact that *U. eichhorniae* occurs only in its uredial stage on waterhyacinth through most of the year points to cyclic nature of its uredospore infections. The predominant source of inoculum for infections would have to be the uredia. Maximum incidence of *U. eichhorniae* occurred in Argentina in the fall, under cooler temperatures and average RH above 75 percent. It is apparent that the climate in southeastern United States would be favorable for the establishment of this rust in this country.

Laboratory experiments on "U. eichhorniae." Results of spore collection and germination tests and host inoculation are described below.

a. *Spore collection.* For our experimentation, uredospores of the waterhyacinth rust were collected from fields in Argentina and Uruguay or obtained from live, rust-infected plants transported to Gainesville from these countries. The lack of abundant supplies of uredospores is presently a limiting factor in our research. So far, most viable collections of spores have been obtained from fresh, field-collected plants with the aid of a cyclone spore collector. Uredospores must be obtained from open uredosori. Uredia differ in age, and not all uredosori on an infected plant are open at the same time. When immature sori were forced open, they did not yield viable spores. Even open pustules yield only a small percentage of apparently mature spores at a given time, which leads to low spore germination percentages in our tests. In addition, uredosori of *U. eichhorniae* are often parasitized by another fungal pathogen, *Darluca* sp. Such infected uredosori must be avoided in the collection of uredospores, since the presence of *Darluca* spores in uredospore collections leads to poor or no subsequent germination of apparently mature uredospores.

b. *Spore germination.* Uredospores of *U. eichhorniae* germinated over a wide range of temperatures (5° - 23°C) in the laboratory. Spores germinated readily in H_2O, 0.05 percent nonanol, and 0.05 percent octanol. Germination can be seen as early as 6 hr after seeding on the above liquids. Initial hydration or leaching of spores for 24 hr with water improved subsequent germination of spores on water agar.

c. *Host inoculation*. The shiny surface of waterhyacinth leaf does not seem to retain uredospores easily, especially under high humidity, when water droplets tend to wash away the inoculum applied to leaves. Sticking agents (mineral oils, glycerine, gelatine, and plain agar) were tried.

Best results were obtained with 10 percent glycerine, which was sprayed on leaves prior to dusting with uredospores. High humidity on leaf surfaces is necessary for *U. eichhorniae* infections. Keeping waterhyacinth plants covered with clear plastic bags for 2 to 4 days after inoculation provided high humidity and successful infections. Inoculations on waterhyacinth were accomplished at 20°C (day) and 8°C (night) temperatures. Plants were maintained in growth cabinets under 12 hr of light and 12 hr of darkness. Successful infection and pustule development were obtained with an Argentine isolate of *U. eichhorniae* on a Florida clone of waterhyacinth. This apparent lack of host resistance suggests that it is possible to establish *U. eichhorniae* in Florida. Mr. Daryl McKinney, a graduate student under my direction, is presently conducting research on this rust pathogen in Gainesville.

HYDRILLA

We have reported earlier on the occurrence of pathogens and toxic fungi on hydrilla.[8,9] Freeman[10] is evaluating two pathogenic species of *Phytophthora*, *P. parasitica* and *P. erythroseptica* and an unidentified species of *Phytophthora* from Orange Lake, isolated by Conway, against hydrilla in greenhouse tests. McKinney is testing an isolate of *Fusarium roseum* from Holland on hydrilla. This fungus, isolated from dying *Stratiotes aloides* L. (Hydrocharitaceae) plants near Wageningen by Charudattan, is capable of infecting hydrilla, another member of Hydrocharitaceae, but not waterhyacinth. An isolate of *F. roseum* is known to attack waterhyacinth in Florida.[11] Apparently, this Dutch isolate of *F. roseum* is distinct from the Florida isolate. Further tests with this foreign isolate are planned. Due to limitations in manpower, research on hydrilla has been slow. We hope to rectify this situation with the help of Dr. Mike Olexa, who has recently joined our program to seek and evaluate microbial agents capable of controlling hydrilla.

SUMMARY

Two fungal pathogens of waterhyacinth, *Cercospora rodmanii* and *Acremonium zonatum*, are being tested in fields in the southeastern United States as biological controls for waterhyacinth. Of these the former, *C. rodmanii*, is being considered for mass production and experimental mass releases in the field. Data from these proposed large-scale experimental tests will be used to further assess and possibly register *C. rodmanii* as a fungal biocontrol for waterhyacinth. *Acremonium zonatum*, which is capable of destructive damage on waterhyacinth by itself, is also suited for integrated biocontrol of waterhyacinth in combination with *Neochetina eichhorniae* and *Orthogalumna terebrantis*. In south Florida interaction between these arthropods and *A. zonatum* occurs naturally, but at the existing levels of *A. zonatum* infections, such interaction offers limited control of waterhyacinth in the field. Induction of *A. zonatum* epiphytotics on arthropod-damaged waterhyacinths may efficiently control this weed. Studies on *Uredo eichhorniae*, an obligate rust pathogen on waterhyacinth, have suggested this fungus to be another significant, host-specific biocontrol agent against this host.

ACKNOWLEDGMENT

This research was supported by funds from the U. S. Army Corps of Engineers under Contract No. DACW73-73C-0049, the U. S. Department of the Interior, Office of Water Resources Research, under the Water Resources Act of 1964, and from the Florida Department of Natural Resources under Contract No. 12/13/74 HJ-1. Portions of this research were done cooperatively between the University of Florida and the U. S. Department of Agriculture, Agricultural Research Service at Fort Lauderdale and at Hurlingham, Argentina.

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PRELIMINARY RESULTS OF INTEGRATING CHEMICAL AND BIOLOGICAL CONTROLS TO COMBAT WATERHYACINTH*

by

B. D. Perkins**

ABSTRACT

Treated (2,4-D at 2 lb/acre) and untreated plots of waterhyacinth (*Eichhornia crassipes* (Mart) Solms-Laubach) were sampled monthly from April to October 1976 for plant density, populations of adult weevils (*Neochetina eichhorniae* Warner) per plant, and average number of feeding spots per plant. The herbicide reduced waterhyacinth abundance and was aided in complete elimination of plants in the treated plot by weevils apparently being attracted to plants reacting to the 2,4-D treatment.

INTRODUCTION

The concept of integrated control is not new; it has been used against insect pests for many years.[1-5] Its first use against aquatic weeds combined 2,4-D and the alligatorweed flea beetle (*Agasicles hygrophila* Selman and Vogt) to control alligatorweed (*Alternantha philoxeroides* (Mart) Grisb).[6] The present study summarizes early findings in our effort to integrate imported insects and chemicals against waterhyacinth.

Waterhyacinth (*Eichhornia crassipes* (Mart) Solms-Laubach) is generally a more serious pest than alligatorweed. Although 2,4-D in high enough dosage can kill the plant, regrowth and reinvasion are rapid, and the public continues to be concerned over large quantities of this chemical contaminating waterways. Thus, an alternative approach, use of no chemical or low-dosage of chemical, is needed. Two weevils, *Neochetina eichhorniae* Warner (released in 1972) and *Neochetina bruchi* Hustache (released in 1974), have been imported from Argentina for biological control of waterhyacinth.[7,8] The weevils alone, however, may not be able to reduce the abundance of waterhyacinth below the economic threshold, and additional control methods—chemical, biological, or other—may be needed. An integrated approach, combining the attributes of both chemical and biological control methods, is possibly the answer. Determination of the effect of the combination of herbicide treatment with use of the weevil is necessary before a control program utilizing the integrated approach can be developed. In the study reported here, a combination of 2,4-D and the weevil, *N. eichhorniae*, which is well established in field sites in and around Fort Lauderdale, Florida, was used.

MATERIALS AND METHODS

A waterhyacinth field site was selected which met the criteria of having (a) an abundance of uniform-sized waterhyacinth plants, (b) a well-established population of the weevil (*N. eichhorniae*),

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* Cooperative studies of the U. S. Department of Agriculture, Agricultural Research Service, Southern Region, Fla-Antilles Area, the U. S. Army Corps of Engineers, the Florida Department of Natural Resources, the Central and Southern Florida Flood Control District, and the University of Florida Agricultural Experiment Stations.

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and (c) a high level of security from spray operations or public interference. Six field plots measuring 8 by 8 m were outlined using nylon cord tied to a floating plastic jug at one corner of each plot and to bunched waterhyacinth petioles at each of the other corners. Three plots were than sprayed with 2,4-D at 2 lb/acre equivalent, and the other three plots were left unsprayed as controls. Data were taken monthly. Access to the plots was by watershoes (floating pieces of foam plastic with foot holes). Four plants were selected randomly inside each plot and four plants were selected outside the plot, one from each side. Plant size and density, number of adult *N. eichhorniae*/plant, number of feeding spots/leaf, overall plant condition, and other associated organisms were recorded. A square metre measuring tool made from PVC pipe joined at the corners was used to enclose the plants in determining density. Adult weevils, which hide during the day at the base of the petioles, were counted and the number was recorded. An average leaf on each of three plants from each plot was selected, and feeding spots on these leaves were counted and recorded.

RESULTS AND DISCUSSION

Preliminary results to be presented here consist of average number of *N. eichhorniae* feeding spots/leaf, average number of these weevils/plant, and average density of plants (plants/m^2) inside and outside the plots during the months April through late September 1976. Each figure represents an average of data from three plots (replicates).

Figures 1 and 2 indicate plant density as it occurred in the control and treatment plots, respectively. The density of plants outside the treated plots paralleled that inside and outside the control plots. The density of plants decreased markedly from 61 to 2 plants/m^2 inside the treated plots, as would be expected with herbicide application. Interestingly, slight regrowth (up to 15 plants/m^2) had begun by August, but this was heavily attacked by the increasing adult weevil populations, augmenting destruction of these plants.

Figures 3 and 4 indicate the average number of adult weevils/plant of the control and treated plots, respectively. Outside and inside the control plots, adult populations increased steadily from an average of 0.7 and 1.7 adults/plant, respectively, to 2.4 and 3.5 adults/plant, respectively. Outside the treated plots, the adult population decreased initially from 1.5 to 0.3/plant. Inside the treated plots the population initially increased from about 1.2 to 2.5. This indicated movement from outside the plot to the inside. Number of feeding spots produced, as indicated below, followed a similar pattern. At this time, many of the petioles inside the treated plot were elongating, a symptom typical of sublethal 2,4-D treatment. The pale, elongated petioles were heavily fed upon by adult *N. eichhorniae*. The adult population decreased rapidly and steadily thereafter in the treated plots as the plants deteriorated and died, reaching an average of 0.3 adults/plant by mid-September. Commensurate with this decrease, the weevil population outside the treated plots increased, reaching a population level of 2.9 adults/plant, a figure comparable to that of the control plots.

Figures 5 and 6 indicate the feeding spots/leaf produced by *N. eichhorniae* outside and inside the control and treated plots, respectively. Feeding spots outside and inside the control plots increased steadily, from 111 and 105 feeding spots/leaf, respectively, to 202 and 243 feeding spots/leaf, respectively. Feeding spots increased in the control plots and closely followed increase in adult weevil populations. In the treated plots, however, the feeding spots/leaf initially decreased sharply from 113 to 87 outside the plot while increasing from about 110 to 168 inside the plot. This may have been caused by the 2,4-D treated plants becoming attractive to the weevils, possibly owing to release of a kairomone

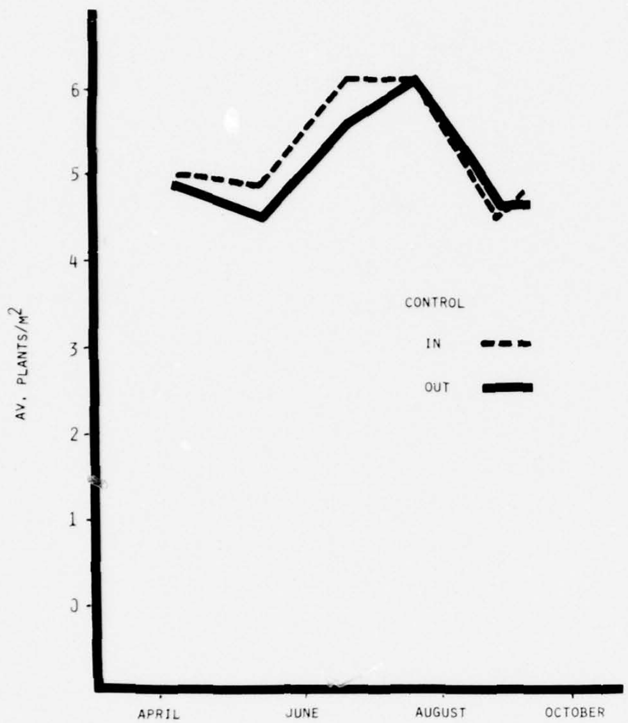

Figure 1. Density of waterhyacinth (average number of plants/m²) inside and outside control plots April through September 1976

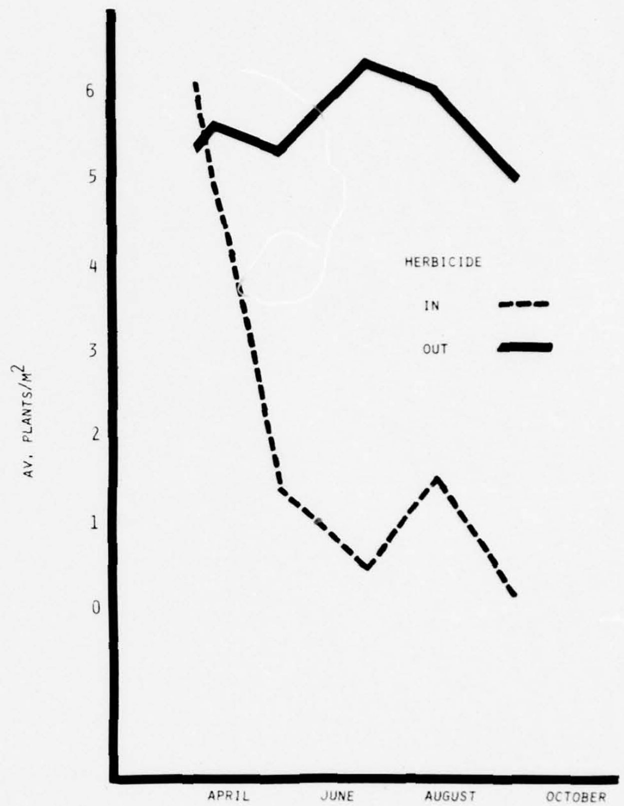

Figure 2. Density of waterhyacinth (average number of plants/m²) inside and outside 2,4-D treated plots April through September 1976

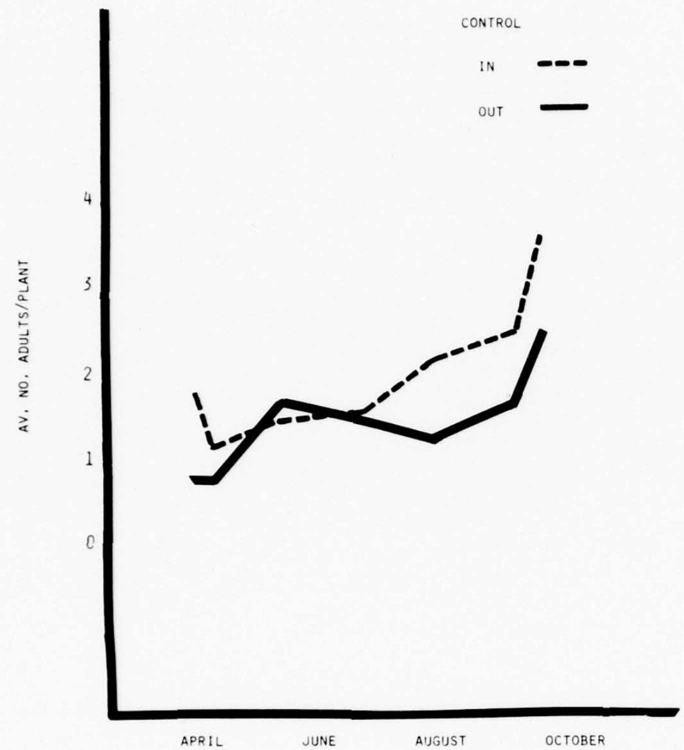

Figure 3. Average number of adult weevils/plant in control plots April through September 1976

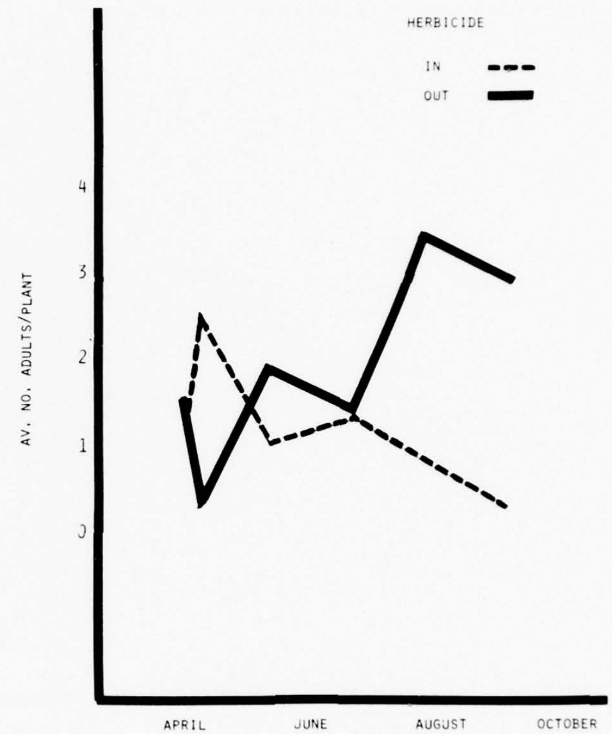

Figure 4. Average number of adult weevils/plant in 2,4-D treated plots April through September 1976

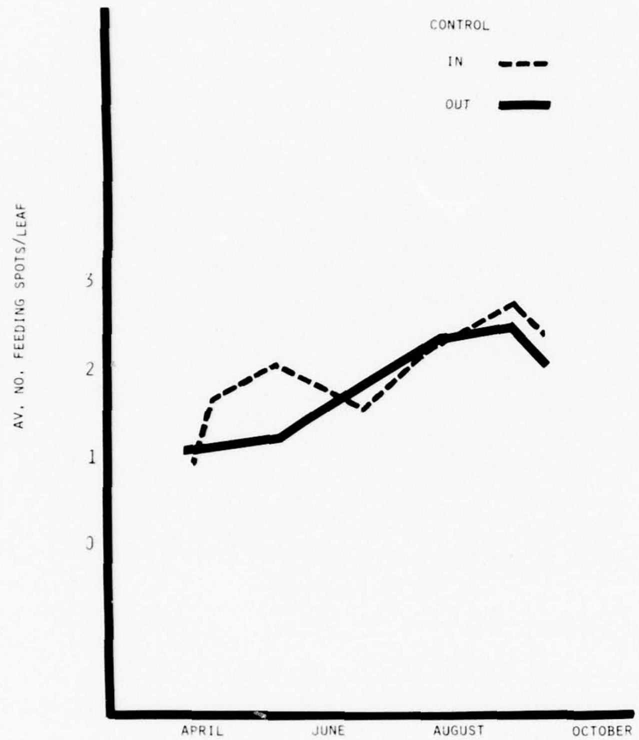

Figure 5. Average number of feeding spots/leaf in control plots April through September 1976

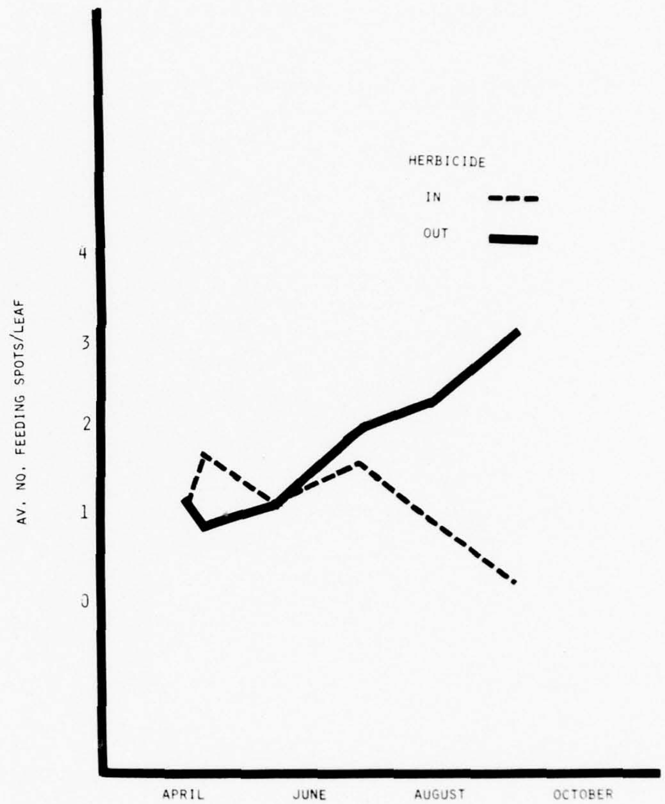

Figure 6. Average number of feeding spots/leaf in 2,4-D treated plots April through September 1976

from growing waterhyacinth tissue.[9] This phenomenon of insects being attracted to plants treated with 2,4-D has been observed previously on crop plants[10] and may be a factor that could be manipulated in biological control of waterhyacinth. Feeding spots inside the treated plots continued to decrease to a level of 26 feeding spots/leaf by September, while those outside the plots increased to 294 feeding spots/leaf, a figure comparable to the control plots in September.

ACKNOWLEDGMENT

Recognition is given to W. C. Durden, Agricultural Research Service technician, Fort Lauderdale, Florida, for his assistance in setting up field plots and taking and analyzing data.

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CONTROLLED FIELD TESTS OF SELECTED INSECTS AND PATHOGENS IN COMBINATION ON WATERHYACINTHS

by

E. E. Addor*

INTRODUCTION

In May 1975, the U. S. Army Engineer Waterways Experiment Station (WES) initiated a small-scale experiment for biological control of waterhyacinth (*Eichhornia crassipes* (Mart) Solms) with multiple agents on Lake Concordia, in Concordia Parish, Louisiana (90° 31′ longitude, 31° 40′ latitude, approximately). Sixty-four floating plot frames were placed on the lake and stocked with young, vigorous waterhyacinth plants collected from the waterhyacinth population that grows naturally near the margins of this lake. The plots were then anchored at 20-ft intervals on cables stretched between widely spaced trees in otherwise open water near the upper end of the lake (Figures 1 and 2**). The plot frames are described briefly in Appendix A of this paper.

On 60 of these plots, two insects and two fungi were used as treatment; 4 plots were used as controls. Sixteen possible combinations of the insects, fungi, and no treatment (controls) were applied in a 2^4 factorial random-block experiment, with four replications of each treatment.[1] The random-block design was derived from a quasi-latin square (Figure 3).

The two insects used in these tests were *Arzama densa* Walker and *Neochetina eichhorniae* Warner. The first is a noctuid moth related to the cutworms and corn borers, native or naturalized in the United States and specific to plants of the waterhyacinth family (Pontederiaceae) but apparently seldom abundant in any given locality.[2-4] The second is a weevil introduced from South America and recently released in the United States in a few places for field trials, mostly in Florida.[5,6] *Neochetina*† is specific to waterhyacinths both in the adult and larval stages.

The two fungi are a species of *Cercospora*, earlier thought to be *C. piaropi* Tharp but now identified as *C. rodmanii* Conway[7,8] and *Acremonium zonatum* (Sawada) Gams. Both fungi are native or naturalized in the United States; species of *Cercospora* are widespread and vary as to host specificity and pathogenicity. Earlier observations of *C. piaropi* on waterhyacinths suggested limited pathogenicity, but the isolate now identified as *C. rodmanii* appears to be both specific to waterhyacinths and highly virulent on them.[8] *Acremonium* is apparently common on waterhyacinths throughout the range of that plant.[9,10] It is apparently host-specific to waterhyacinths, but its pathogenicity to waterhyacinths under natural conditions appears to be erratic.[8]

The rationale for using insects and fungi together in this experiment lies in the premise that one or the other, or both, of the insects will reduce the number of waterhyacinths by direct mechanical destruction and consumption of the plants and will enhance the pathogenicity of one or the other, or both, of the fungi. Any of three relations may obtain: (a) the insects may stress plants so that they are more susceptible to infection by the fungi; (b) the insects may transport the spores or mycellia of the

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** Ninety-seven plots were actually prepared, but only 64 were used in the original experimental array. The remaining 33 were anchored in clusters in the test area; they are shown in Figure 2 as "spares." These were subsequently incorporated into the experiment but are of small consequence to the results reported in this paper.

† In this paper, the test organisms are called by their generic names; the species identified in this paragraph are implied.

Figure 1. Portion of test plot array, Lake Concordia, viewed easterly from barge (Figure 2). Photo taken 12 August 1976 (Row D in foreground), showing depauperate plants in some plots

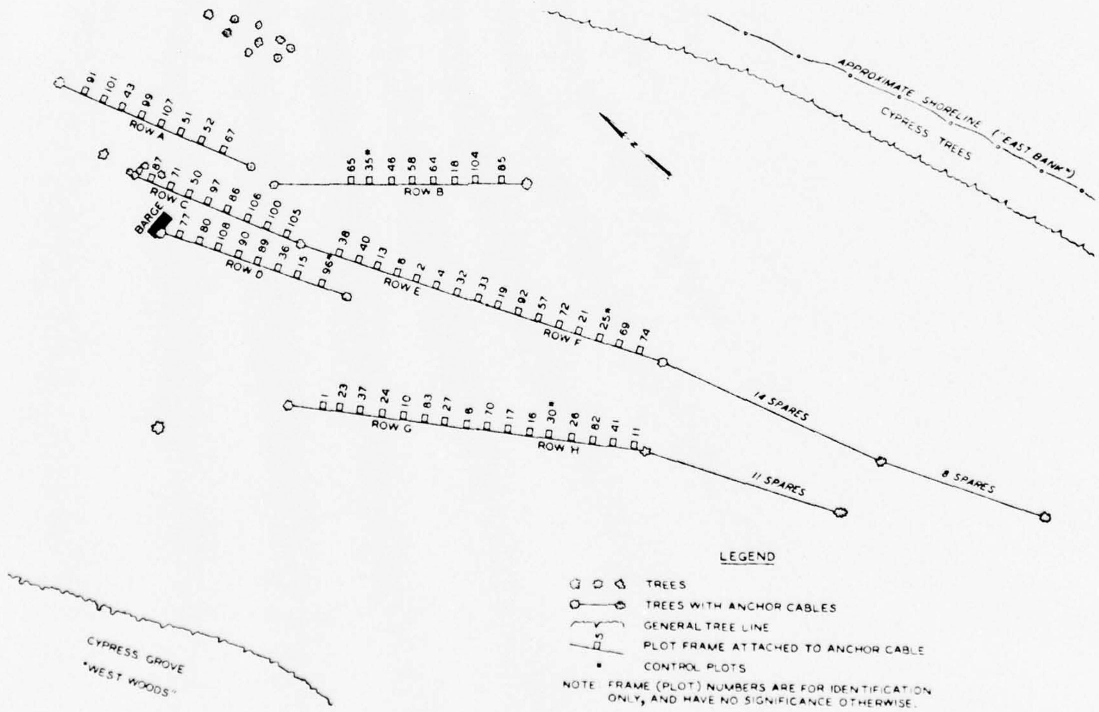

Figure 2. Field map of test plot array, Lake Concordia, 1975

Row Pair	Row	Treatment							
I	A	c	abcd	b	ad	a	bd	abc	cd
	B	abd	0	bcd	bc	acd	ac	d	ab
II	C	d	bc	a	abcd	b	cd	abd	ac
	D	bcd	ad	acd	bd	abc	ab	c	0
III	E	a	bd	c	ab	d	abcd	acd	bc
	F	abc	ac	abd	cd	bcd	0	b	ad
IV	G	b	ab	d	ac	c	ad	bcd	abcd
	H	acd	cd	abc	0	abd	bc	a	bd

NOTE: a = *Arzama*; b = *Neochetina*; c = *Cercospora*; d = *Acremonium*; and 0 = controls.

Figure 3. Basic plan for 2^4 factorial quasi-latin square experiment with four replications per treatment, adapted from Cochran and Cox[1] for the Lake Concordia experiments

fungi as they move about, on, and through the plants; and (c) the insects may increase the opportunities for entry of the fungi into the plants' tissues through feeding wounds. These particular insects and fungi were selected for the experiment on the basis of their performance as potential control agents for waterhyacinths in recent laboratory and field trails.

The hypothesis to be tested, of course, is that some combination of these insects and fungi will result in a general debilitating effect, i.e. an epiphytotic, on the waterhyacinth population, and the factorial design of the experiment was intended to elucidate the relative contribution of each combination of agents to the resulting epiphytotic.

PROCEDURES

The methods of collecting, preparing, and applying the organisms will be described in detail elsewhere. Briefly, the *Arzama* were released as first instar larvae from second-generation cultured eggs, at the rate of 50 larvae per plot. The *Neochetina* were released at the rate of 150 per plot, as adults collected from naturalized populations near Fort Lauderdale, Florida. The fungi were cultured from collected spores and applied as mycelial suspensions. The cultured mycelia were ground into a concentrated suspension, then diluted for spraying. Each designated plot was sprayed on each of two consecutive evenings, at the rate of 80-g concentrate per plot of *Cercospora* and 160 g of *Acremonium*.

The plots were initially stocked with hyacinths on 27-28 May, the fungus inoculations were made on 24-25 June, and the insects were released on 10 July. The initial release of *Arzama* was subsequently determined to have failed, and a new release of that insect was made on 13 August. The plots were first weighed on 23-24 June and at approximately 2-week intervals thereafter until frost. The weighing apparatus is described briefly in Appendix A. At each weighing the height of the plants was measured, and the plots were inspected for insect and pathogen activity and were photographed. They were left on the lake during the winter, and measurements and observations were resumed in the spring of 1976.

TEST RESULTS

Obviously, the selection of the test design was based on the supposition that an analysis of variance

would reveal the relative contribution of each agent combination to the demise of the waterhyacinths, and indeed such an analysis has been run on the data for the first season. The results of this analysis have not been examined carefully, but on first inspection, they do not appear to be definitive. In fact, the accumulated data are by no means as simple and straightforward as they were intended to be, according to the test design, but instead are confounded by an assortment of experimental problems and unanticipated extraneous influences.

The remainder of this paper consists of a subjective evaluation of the results of the experiment in terms of height growth and weight changes after two growing seasons and a discussion of the insect and pathogen population dynamics. Selected data from the two seasons are presented in Figures 4 and 5. These figures are explained below, and the explanations are followed by the evaluation and discussion mentioned above. It will become apparent from these discussions that alternative analytical procedures will be required if the results of the tests are to be elucidated quantitatively.

Explanation of Figure 4

Figure 4 is a schematic map of the test area showing the chronology of plant height and organism presence at selected times or during selected periods of time during the 2 years of observation. The map shows the test plots as squares with their identification numbers,* in approximately correct positional relation, except the horizontal scale is greatly compressed (Figure 2). *Above* each plot symbol are four vertical bars showing plant heights at four selected times, and *beneath* the plot symbol are some letter symbols representing observations on insect and pathogen activities for the two seasons.

The first two vertical bars above each plot represent the average heights of the plants in the plot on 7 July of the first season (1975), about 40 days after the original stocking, and on 30 September of that season, respectively. The third and fourth height bars above each plot represent, respectively, the height of plants on the plot on 16 July and 15 September 1976, which approximately correspond with the July and September dates shown for the previous season.

The letter symbols on the figure, representing insect and pathogen activity for the two seasons, are arranged in two columns of single symbols, and beneath these, a single column of one or more symbols. The symbols are a, b, c, and d, for *Arzama*, *Neochetina*, *Cercospora*, and *Acremonium*, respectively. The two columns of single symbols are data for 1975, and the single column is for 1976. Of the two columns of data for 1975 under each plot, the first (on the left) represents the designated treatment for the plot according to the original test plan (Figures 2 and 3), and the second column (on the right) represents the organisms that were actually observed on the plot at sometime during the 1975 season, irrespective of date except exclusive of the dates of application. A dot in the place of a, b, c, or d in either of these columns indicates that the missing organism was not applied to that plot, or was not subsequently seen on the plot during 1975, as the case may be. (Note that plots 35, 25, 96, and 30 are the untreated control plots.) For the 1976 data, the symbols show the observed organisms present at two selected inspection dates, 23 June and 16 July, respectively.

Finally, the arrows between the columns for 1975 indicate the nearest potential source of contamination when one of the test organisms, not applied to a plot, was found on it at sometime during that season. When a potential source of infection is equally near from either direction, the direction of the arrow is arbitrary.

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* These identification numbers have no significance to the test design.

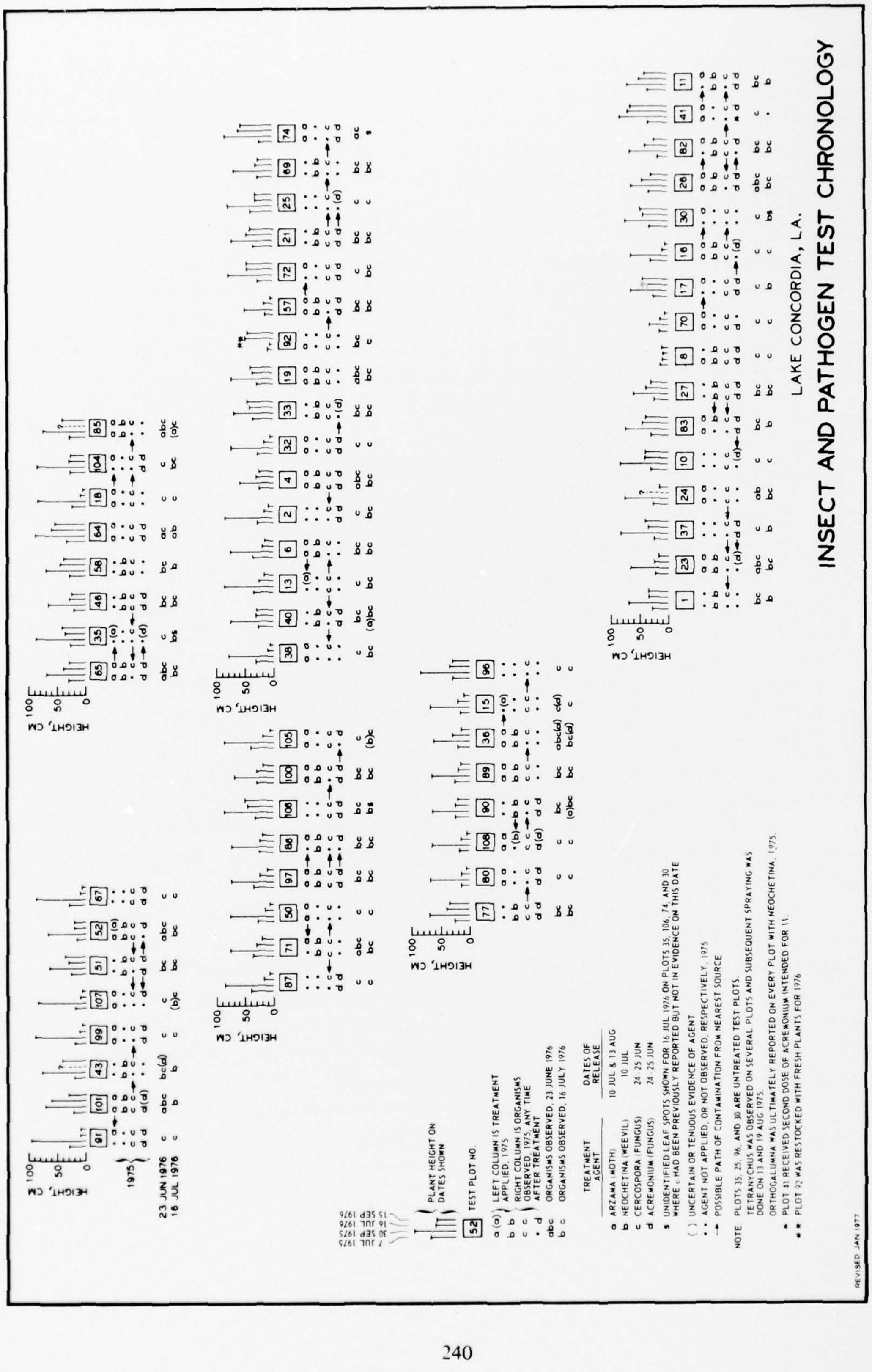


Figure 4. Chronological summary of insect and pathogen activity and periodic plant height, 1975-76

Explanation of Figure 5

Figure 5 presents four graphs for four selected treatments (a, ab, abc, and abcd). These graphs show plot weights averaged for the four replicates at each weighing, from the first weighing of the first season to the most recent weighing available at the time of writing, compared in each case to the average weights of the four control plots.

Explanation of Figures 6-11

Figures 6-9 are sequential photographs of selected plots, showing growth and deterioration through the two seasons. These were selected arbitrarily to illustrate the variations in patterns and rates of development and deterioration among the plots. No attempt has been made at comparative representation of any particular treatments or contamination effects. (The organism activity histories can be construed from data in Figure 4.) Each set of six photographs starts with the healthy pretreatment plants on 23 June 1975, followed by two photographs at subsequent times during that season. The fourth photograph (d) in each set shows the early spring regrowth in the second season, 25 May 1976, and these again are followed by photographs on two subsequent dates during that season.

Figure 10 presents details of plants from the plots shown in the preceding four figures. All of these except the sixth photograph (f) were taken on 17 September 1976. This photograph (f) shows the winter condition of plot 105, which is typical for the test plots and for the naturalized population in the lake, and the surviving green under protection of the winter mat. By early May, the dead material will have decayed and sifted out of the plot (cf. d in Figures 6-9).

Figure 11 shows some general views and details of plants from the naturalized waterhyacinth population on the lake after midseason of 1976. In the first three photographs (a-c) of this figure, the area referred to as "west woods" is a baldcypress grove in shallow water (less than 1 m deep in midseason) on the westerly side of the lake (Figure 2). It is contiguous with the extensive cypress grove at the upper end of the lake (southerly from the test area). In the vicinity of the test area, it is perhaps a hundred metres wide and continues so for a few hundred metres northerly from the test area. In past years, it has supported a dense vigorous growth of waterhyacinth. The "east bank" in the fourth and fifth photographs (d and e) drops more sharply into deeper water, and the waterhyacinth here is confined to a narrow band not normally exceeding 10-20 m in width. In the fourth photograph (d), the plants showing the intensive yellowing are mostly on the shore between "normal" waterline and the midseason low waterline, and the greener plants are confined almost immediately to the waterline.

Discussion of Growth Responses (Height and Weight)

The height data in Figure 4 clearly show that, in July of 1975, the newly stocked plots were only at the beginning of their growth surge for that season, and they continued to grow vigorously into September of that year; whereas in 1976, the height growth on most plots apparently had peaked by mid-July and even declined somewhat on several plots after that time. This trend is also reflected in the weight data for the 2 years, as shown in Figure 5. Note that the average weight gain *rate*, indicated by the slope of the graph, is, for all of the treatments shown, considerably slower for the second season than for the first, and the peak of the graph (maximum average weight) occurs much earlier in the second season than in the first (August versus September, respectively).

It is possible to argue from these data that the treatments chosen for illustration, except "a" (*Arzama* only), have suppressed the growth of the plants on the test plots. However, another relation is

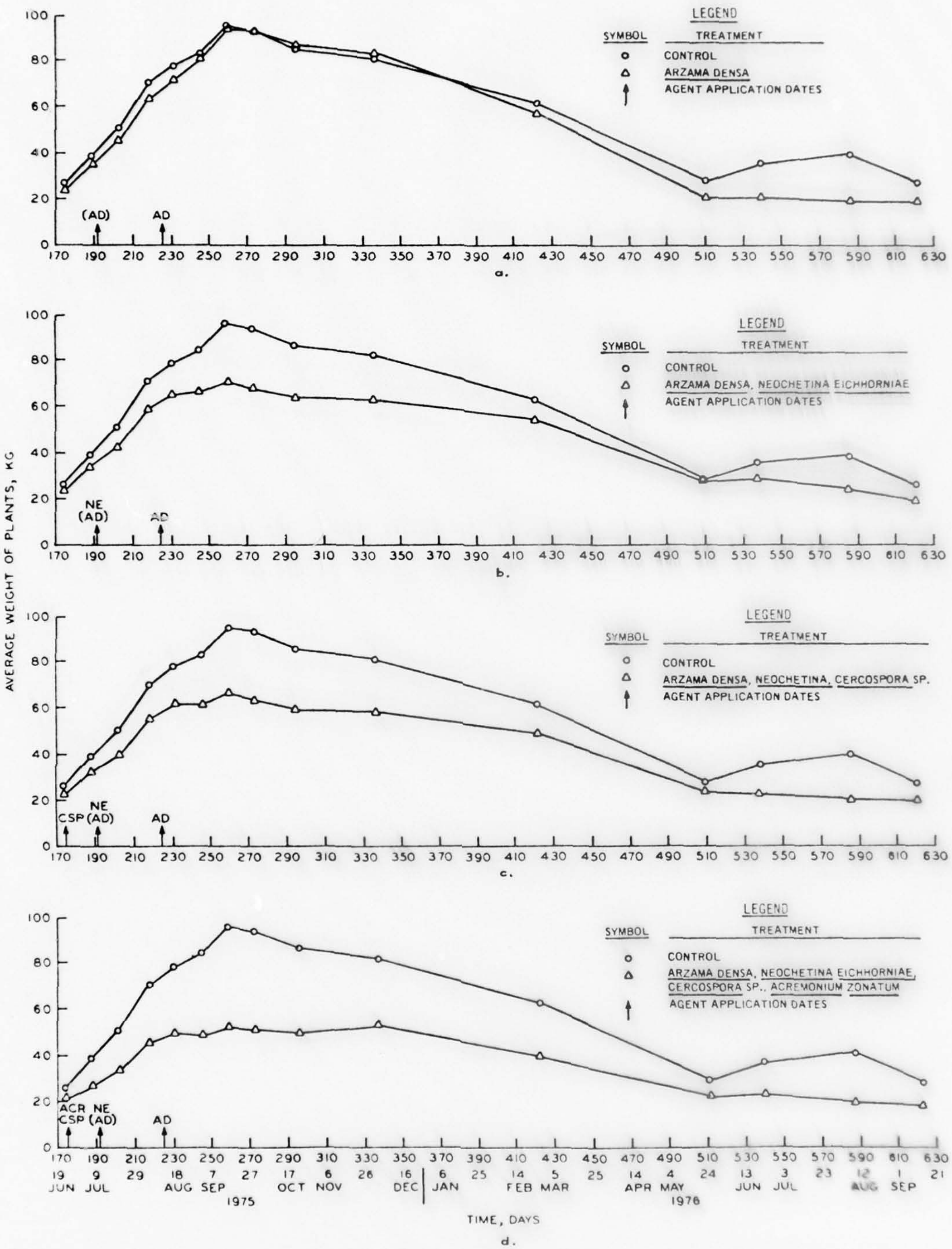


Figure 5. Plot weight versus time for four selected treatments compared with the controls, 1975-76. Weights shown are the averages of the four replicates for the respective treatments

a. 23 June 1975

b. 5 August 1975—*Neochetina* feeding scars

Figure 6. Sequential photographs, plot 43
(sheet 1 of 3)

c. 19 August 1975—*Neochetina* feeding scars and yellowing of leaves

d. 25 May 1976—spring regrowth, with *Neochetina* scars

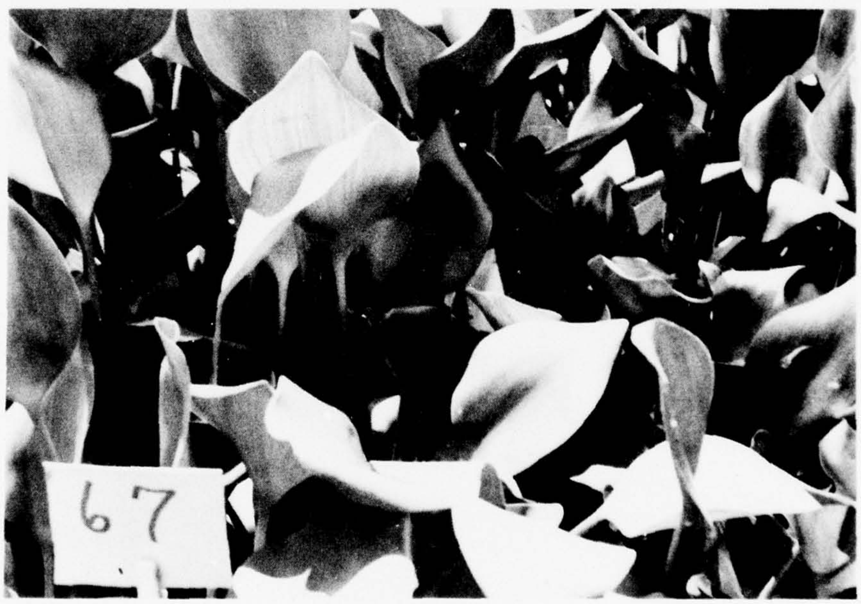
Figure 6 (sheet 2 of 3)

e. 12 August 1976—general pale coloration

f. 26 October 1976—severe dieback of previously yellowed leaves

Figure 6 (sheet 3 of 3)

a. 23 June 1975



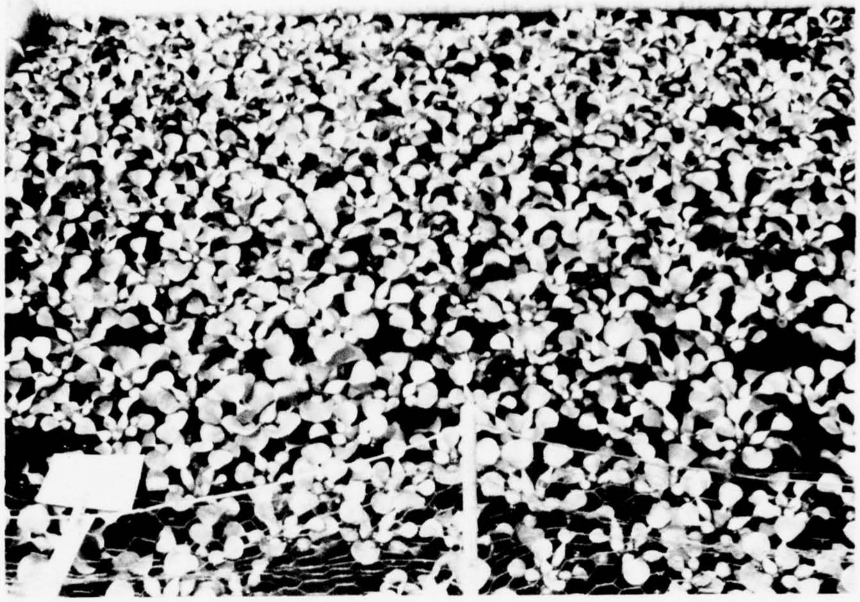
b. 19 August 1975—severe yellowing of some leaves

Figure 7. Sequential photographs, plot 67
(sheet 1 of 3)

c. 23 October 1975—dieback of previously yellowed leaves

d. 25 May 1976—spring regrowth

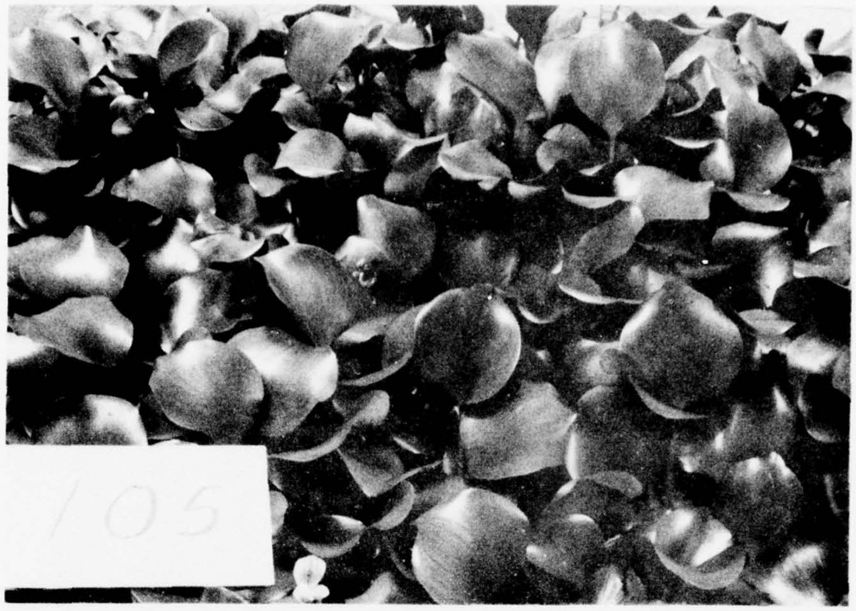
Figure 7 (sheet 2 of 3)



e. 12 August 1976—this plot failed to develop beyond float-leaved stage

f. 17 September 1976—observe deteriorating condition, which continued into winter

Figure 7 (sheet 3 of 3)

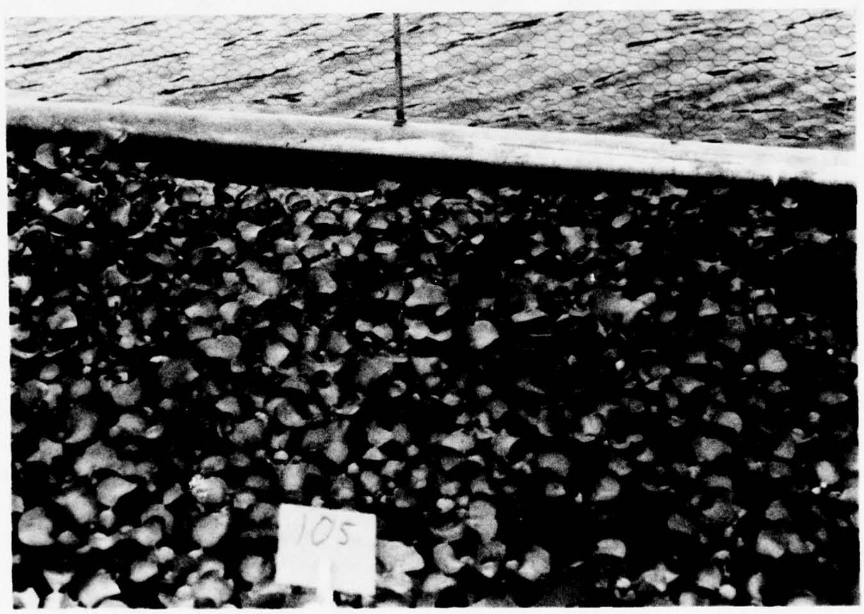


a. 23 June 1975

b. 5 August 1975—plants are relatively vigorous (Figure 7b)

Figure 8. Sequential photographs, plot 105 (sheet 1 of 3)

c. 2 September 1975—general yellowing



d. 25 May 1976—spring regrowth

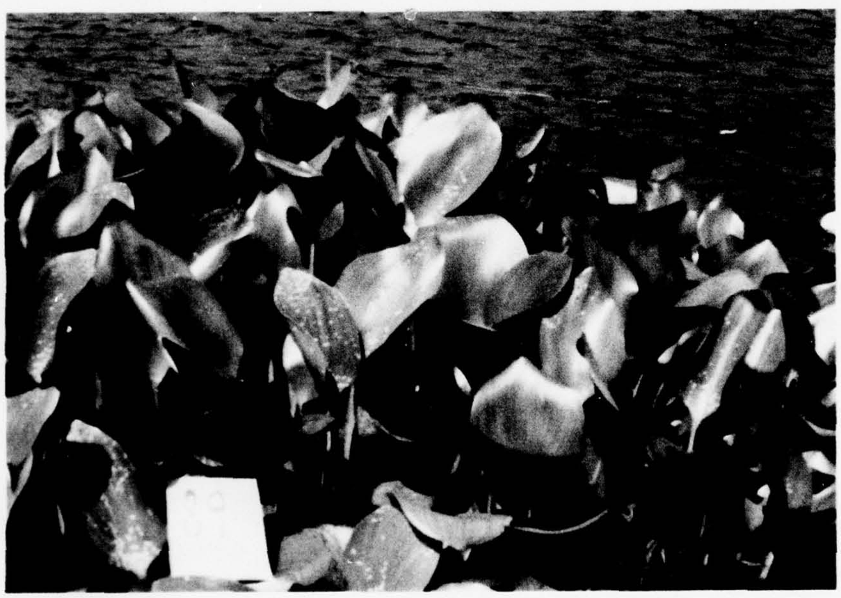
Figure 8 (sheet 2 of 3)

e. 24 June 1976—general yellowing

f. 17 September 1976—decline continued into winter

Figure 8 (sheet 3 of 3)

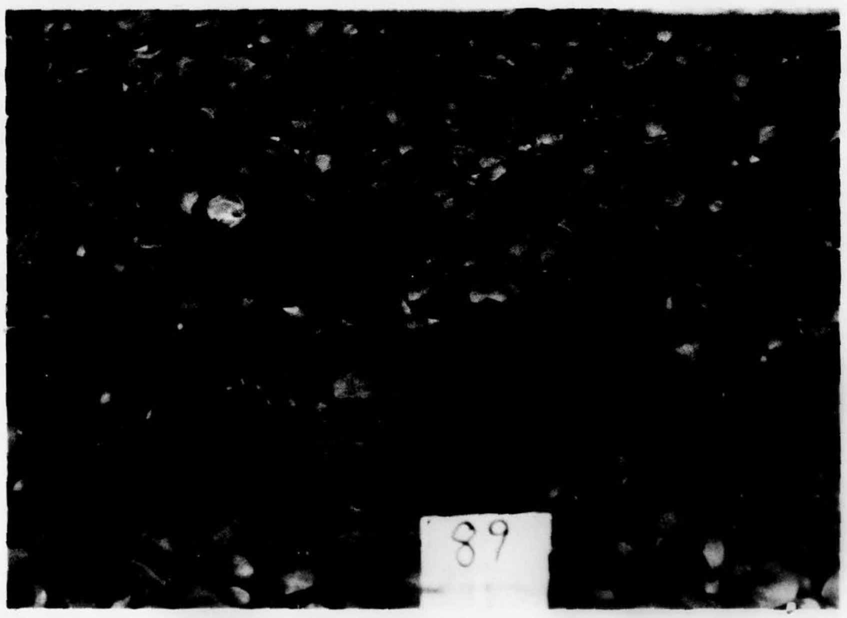
a. 23 June 1975



b. 21 July 1975—*Neochetina* feeding scars

Figure 9. Sequential photographs, plot 89
(sheet 1 of 3)

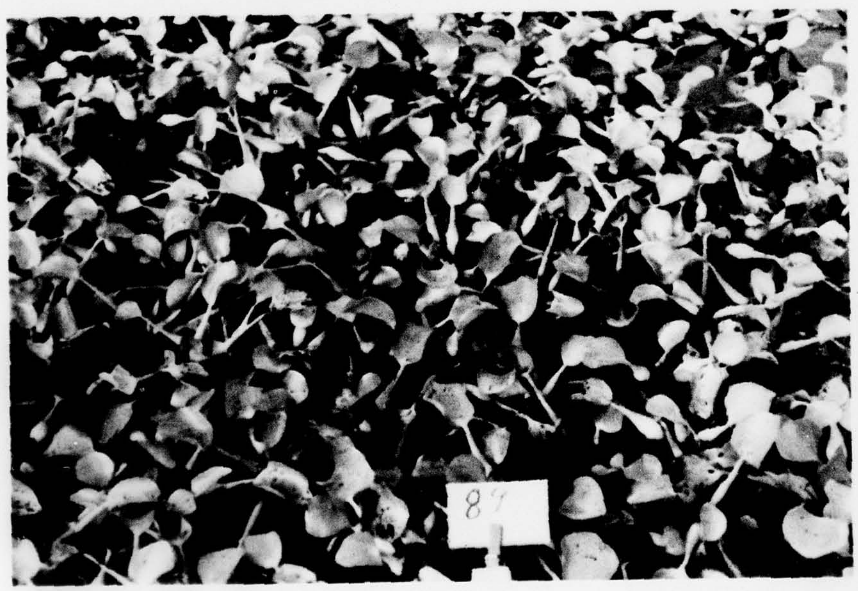
c. 30 September 1975—*Orthogalumna* and *Cercospora*



d. 25 May 1976—spring regrowth

Figure 9 (sheet 2 of 3)

e. 18 September 1976—this plot had attained height but is now experiencing severe dieback. *Neochetina* feeding scars and *Cercospora* are conspicuous



f. 26 October 1976—decline continued, and some plants reverted to float-leaved stage

Figure 9 (sheet 3 of 3)

a,b. Plot 43, 17 September 1976 — browning of petiole and leaf blade following severe yellowing. The condition is tentatively called "brownout"

Figure 10. Plant details from plots 43, 67, 105, and 89 (Figures 6-9) (sheet 1 of 3)

c. Plot 67, 17 September 1976—depauperate plants showing severe necrosis of leaf tips and extensive decay of leaf blades and petioles

d. Plot 89, 17 September 1976—advanced decay following "brownout"

Figure 10 (sheet 2 of 3)

e. Plot 105, 17 September 1976—advanced decline as in plot 89, with reversion of plants to float-leaved growth phase

f. Plot 105, 26 February 1976—winter frost kill, typical for the test area

Figure 10 (sheet 3 of 3)

a. General view in baldcypress grove, "west woods," 16 September 1976. This area was earlier covered with waterhyacinth

b. Closer view of deteriorating plants in a

Figure 11. General views and details of naturalized waterhyacinth population on Lake Concordia, 1976 (sheet 1 of 3)

c. Details of leaf blades and petioles from plants in b. Damage appears to be due to *Neochetina* (observe scars on blade), *Arzama*, and *Cercospora*, accompanied by "brownout"

d. On "east bank" about 1 km west of experiment site, 12 August 1976. *Neochetina* and *Cercospora*, with severe yellowing

Figure 11 (sheet 2 of 3)

e. Same place as d, 17 September 1976, showing boreholes in petioles and typical "brownout" symptoms

Figure 11 (sheet 3 of 3)

also conspicuous on the graphs shown in Figure 5, viz., although the suppression of growth on the treated plots with respect to the controls occurs in both seasons, the growth on the controls themselves is suppressed during the second season with respect to the first. Various hypotheses may be advanced to explain this phenomenon, some of which may be tested with existing data, and some of which must await additional observations.

Thus, for example, it could be argued that the phenomenon was due to a seasonal difference in the growing conditions (climatic or aquatic) at the test site, and indeed the random block test design is intended to account for just such differences. However, height measurements on the nominally untreated "spare" plots during 1976 (data not shown here) suggest that the growth on these was accelerated, not suppressed, during the second season relative to the first. Alternatively, since the spare plots were not molested, i.e. raised and drained periodically, during the first season, it may be argued that molestation of the test plots, including the controls, during the first season affected the subsequent vigor of the plants on these plots. This hypothesis cannot be tested with existing data. There is not space here, nor sufficient data at hand, to pursue various other possible explanations of the phenomenon; but on considering the evidence in hand, we tentatively reject any other explanation and accept the conclusion that it results from activities of biological agents, including, but not necessarily limited to, the test organisms. Tentative support for this conclusion appears in Figure 4, which shows that none of the control plots escaped contamination by at least one test agent during the first growing season, so that all of the control plots are effectively treated plots insofar as data from the second season may be taken as being statistically valid.

Figures 6-10 show clearly the general deterioration of the plants associated with declining growth rates and losses of height and weight on the test plots.

Discussion of Population Dynamics

It is seen from the data in Figure 4 that extensive migrations of the test organisms occurred during the first season after application, resulting in extensive cross-contamination of the test plots, including the designated controls. In many cases, this occurred sufficiently early in the season (not evident from the data presented) as to render the actual treatment of the plot different from the intended treatment, even for the first season. In addition, there are a few cases in which the applied treatment organisms apparently failed to become established and were subsequently never seen on the plots.

In summary, it is seen that by the end of the 1975 season:

a. *Arzama* was observed on 12 plots where it had not been applied, including two of the control plots.

b. *Neochetina* was observed on two plots where it had not been applied.

c. *Cercospora* was observed on 32 plots where it had not been applied (by the end of the season it was reported on every plot including the four controls).

d. *Acremonium* was observed on 11 plots where it had not been applied, including two of the control plots.

Conversely, however, during that season:

a. *Arzama* was *never* observed on two plots to which it had been applied (plots 92 and 8; the "inherent" low vigor* of these two plots may account for this failure).

b. *Acremonium* was never observed on one of the plots to which it had been applied (plot 70).

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* An unexplained and perplexing phenomenon.

In every case, except three cases for *Cercospora*, contamination could have occurred from an immediately adjacent plot. In fact, there has been a problem with the plots becoming unleashed from the anchor cables (the ropes rot through, and the snaps rust out)* and drifting along the anchor cable to rest against their neighbors. No record has been kept of these occurrences, but it is improbable that it would account for all cases of contamination. It has also been ovserved that fragments of plants may be broken from a plot during the weighing process and transported to the next plot on the lifting frame of the weighing apparatus.

Other possible processes for contamination, in addition to "natural" dissemination (by flight for adult insects, or wind and water for fungus spores), would be from plants escaping from the treated plots and drifting about, or from vagrants from the naturalized population drifting about among the plots. The latter is an especially common occurrence; such plants often collect against a plot, where they may rest for sometime before being moved away by wind or waves or by the experimenters prior to weighing the plot.

There is reason to suppose that all of these methods of dissemination were at work in the test area, since the organisms spread extensively into the naturalized waterhyacinth population, as will be described below. Whatever the cause, it is evident that the test plots were sufficiently contaminated, even during the first season, as to render suspect any conclusions based on uncritical statistical analysis of the data.

Figure 4 shows further that all of the test organisms, except *Acremonium*, survived through the winter and became active again early in the second season. *Acremonium* was never reported to be strong on any plot in the first year (1975) though it did at least become established on most plots to which it was applied, and it was still present on most of those plots on 16 September. At that time, *Cercospora* had not yet spread extensively and had not been reported to be especially strong on any plot. But on 31 October of that first year, *Cercospora* was reported to be widespread through the test area and strong on most plots, while *Acremonium* was nearly extinct on most plots. *Acremonium* was reported tentatively on a few plots on 23 June of the second year, but that identification was not confirmed, and it was never again reported during that season. *Cercospora*, by contrast, reappeared virgorously in the second season and, at the end of the season, was profuse throughout the test plots and on the naturalized populations of hyacinth in the area.

Arzama was observed only sporadically after application in the first season, and indeed the first release on 10 July was declared a failure, so a second release was made on 13 August. However, large *Arzama* larvae were reported on some of the plots on 20 August, only 7 days after the second release, and not all the plots so reported were designated *Arzama* plots (e.g. plots 86 and 11). Whether these larvae were from the first release or native, or both, is of course moot. A large larva was found on one of the plots during a spot inspection in February of 1976, and at that time good evidence of feeding by *Arzama* was also seen in the naturalized waterhyacinth population near the north shore of the lake adjacent to the test area. Note that it reappears sporadically in 1976, most often on plots with the taller plants (e.g. 101, 64, and 85). Damage by *Arzama* was also obvious during the second season on the naturalized waterhyacinth population in the area, but again only on very tall, lush plants or plants that were apparently lush at the time of attack. It does have a severe debilitating effect on such plants, however, as shown in Figure 11a-c.

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* See description of plots in Appendix A.

Neochetina became well established during the first season but exhibited very little transmigration during that year. It reappeared very early in the following spring and was very soon widespread throughout the test plots (e.g., its distribution on 16 July in Figure 4). It also appeared early in the second season on the naturalized waterhyacinth population on the lake and soon spread extensively through that population (Figure 11c-e).

It was implied above that certain organisms other than the test organisms may have played a significant role in the test results. Two especially require comment. These are *Orthogalumna terebrantis* Walwork, waterhyacinth mite, and *Tetranychus cf. gloveri* Banks, a "timid" spidermite, which are not shown in Figure 4.

Orthogalumna began to appear on the test plots on 20 August of the first season. No attempt was made to control this mite, and by the end of the season, it was reported to be on every plot with *Neochetina*, but only on those plots. *Tetranychus* was first reported on several plots on 8 August 1975, being well established at that time. The infested plots were sprayed with an acaricide on 13 August and again on 19 August, and the mite was not reported on any plot thereafter.

Orthogalumna was reported present again in the second season on 11 August, and it developed rapidly thereafter. By 15 September, it was distributed profusely over the test plots, but its specific association with *Neochetina* has not yet been examined. By September of the second season, *Tetranychus* had not yet reappeared on the test plots, though it was present on the native populations of waterhyacinth in the area. (As this paper is being revised for the press, it can be added that *Tetranychus* did not reappear on any of the test plots during the second season, but it did occur on some newly established plots that were set up in the test area as part of another experiment. Whether this mite is limited in its migratory capabilities or selective as to vigor or physiological qualities of its host plants is undetermined.)

CONCLUSIONS

We are not yet prepared to draw definitive conclusions from these data. It is obvious that *Arzama*, *Neochetina*, *Cercospora*, and *Orthogalumna* did survive the first winter in the test area and became reestablished vigorously in the second growing season. It also appears that some combination of the four, in some yet undetermined time sequencing, is capable of establishing and sustaining a debilitating epiphytotic on waterhyacinths under the conditions of these tests and, more generally, under the climatic and other environmental conditions of the test area (Figure 11). The epidemiology of this epiphytotic is not clear, but tentatively it appears that *Arzama* attacks the most vigorous plants, causing considerable physical damage and rendering them susceptible to severe fungus infection. *Neochetina* also attacks mainly the more vigorous plants, and the virulence of *Cercospora* appears to be significantly enhanced by the activities of these insects.

Because of its close association with *Neochetina* in these tests, the role of *Orthogalumna* in this epiphytotic is not obvious and cannot be determined from the data so far collected. Previous attempts to assess the potential of this organism as a control agent for waterhyacinth have been inconclusive.[11-13] Subjectively observed, it appears to have exerted significant stress on the plants in these tests.* Also,

* Significantly, there may be no urgent practical value in attempting to separate the relative effects of these two organisms. It is presumed that *Orthogalumna* was introduced to these plots inadvertently with the *Neochetina*, and there is some evidence that the former bears a commensal relationship with the latter.[12] It may, therefore, be promulgated as operational policy that when *Neochetina* is to be released on a site for control of waterhyacinths, the adults collected for release should be taken from a locality known to be infested also with *Orthogalumna*. Any stresses imposed by these on the weed population, above the stresses imposed by the weevils per se, may then be accepted as serendipitous. The converse also applies.

until the data are more carefully analyzed, the possible role of *Acremonium* early in the first season should not be dismissed, but on first blush it does not appear to have made an important contribution to the general epiphytotic.[8]

Finally, there is some evidence not discussed here but included in the data and shown in the figures (e.g. Figures 10 and 11), that other microorganisms not included in the test set (various unidentified fungi, bacteria, and viruses) may contribute significantly to the epiphytotic.* This possibility also needs to be examined.

PROGRAM PLANS

We are at present investigating the feasibility of putting all of the collected data on INFONET, which is a commercial data storage and analysis service offered by Computer Science Corporation. The WES computer facility is connected with this system, and the stored data would be accessible through a teletype terminal. The system is coupled directly to a statistical library, and it also has graphic output capability. This would allow the test plots to be sorted and regrouped into subpopulations, according to any assortment of criteria that may be of interest, and analyzed for statistically significant relations. Most important, the analyses could be efficiently reiterated through any time period or over any time lapse. It is expected that through this process the epidemiology of the epiphytotic in the test area may be elucidated.

It is now expected that the test plots will be left in place again through the forthcoming winter, and observations will be resumed and continued through at least one more growing season.

ACKNOWLEDGMENTS

This experiment was initiated and designed cooperatively among the WES, the U. S Department of Agriculture (USDA) Biological Control Laboratory at Gainesville, Florida, and the University of Florida (UF) Department of Plant Pathology at Gainesville. We gratefully acknowledge the advice and assistance of Mr. N. R. Spencer and Dr. T. D. Center (USDA), Drs. T. E. Freeman and K. E. Conway (UF), and Mr. Victor Chew, UF Statistics Department. We especially acknowledge the cooperation of personnel at the Louisiana Wildlife and Fisheries Commission Field Station at Lake Concordia for permission to use the lake and their boat docking area and storage facilities and for numerous other kindnesses.

* A condition tentatively called "brownout" may be attributed to these causes. It is illustrated in Figures 10a, b, and d, and 11c and e. It is typified by necrotic streaks extending along the petiole in both directions from insect boreholes (*Neochetina* exit holes?), accompanied by severe loss of chlorophyll and eventual necrosis of the leaf blade. As the disease progresses, the petiole aerenchyma becomes saturated with water, and the plant begins to sink (note that the water level on the plants in Figure 10a and b is well above the root crowns, as indicated by algae incrustations on the petiole). Complete death and decay follow rapidly as the plant sinks. These symptoms are similar to symptoms described by Charudattan et al.[14] The white spots on the leaf blades in Figure 7b are unidentified. Similar spots were seen on various terrestrial species in the area and were thought to be caused by defoliant drift, but this is unconfirmed. They are apparently inactive.

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APPENDIX A
DESCRIPTION OF TEST APPARATUS

The floating plot frames and the weighing apparatus used in this experiment were designed and constructed by the WES especially for earlier experiments with other proposed waterhyacinth control methods. The plot frames are described in detail in the report on those experiments,[15]* and a detailed description of the weighing apparatus is in preparation for publication elsewhere. They are described briefly in the following paragraphs.

The plot frames (Figure A1) were designed to confine the plants throughout the growing season. Each frame is constructed of 10-cm-diam aluminum pipe welded into a square with inside dimensions of 1.8 by 1.8 m. A 61-cm-high fence of 2.5-cm mesh wire net is mounted on the frames, supported by upright metal rods welded onto the frame; and a 5.8-cm-mesh nylon net is suspended slackly beneath the frame. These are intended to prevent the plants from escaping by being washed over or under the frame during periods of high winds or other violent wave action, as from passing boats. The fence also serves to support the plants in an upright position when they become congested in the plot and enter the vertical growth phase. Each frame weighs between 26.5 and 28 kg, wet. They are equipped with snap-on leashes at two corners and held in position in the test array by being leashed to cables stretched between trees or other suitable anchors. U-bolts are clamped to the anchor cables at specified intervals to catch the leash snaps and thus prevent lateral drift of the plots along the cable.

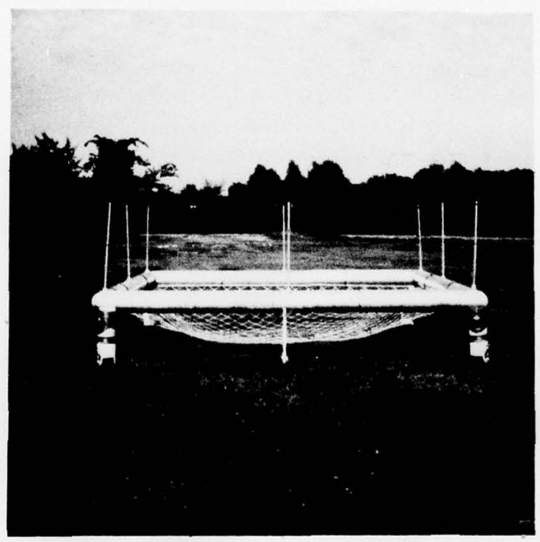

Figure A1. A floating plot frame of the kind used in the Lake Concordia waterhyacinth control tests

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* Raised numbers refer to similarly number items in the References at the end of main text.

The weighing apparatus (Figures A2 and A3) was designed to allow the experimental plots to be weighed efficiently without excessive disturbance. It consists of two flat-bottomed boats in a catamaran

Figure A2. General view of the weighing apparatus used to weigh the frames (Figure A1)

Figure A3. Weighing apparatus in operation, with the test plot suspended through the load cell

configuration, held apart approximately 3 m by a gangplank fixed astern and an A-frame hoist mounted forward. The hoist is equipped with a lifting frame, an electric winch, and a load cell.

The lifting frame is suspended between the boats from the A frame and is of sufficient size as to allow it to be slipped freely under the plot frame. The bottom of the lifting frame is covered with nylon netting to cushion and support the plants as the frame is hoisted from the water to be weighed. The winch is driven by a 12-v, d-c, reversible electric motor and has a lifting capacity of 681 kg. The winch cable is connected to the lifting frame through the load cell, and the load cell is connected to a differential analog amplifier with a digital voltmeter readout, calibrated in kilograms. The assembly is powered by a 15-hp outboard motor mounted centrally on the gangplank; paddles are used for close maneuvering.

Weighing is accomplished by lowering the lifting frame into the water, maneuvering the boats forward to position the lifting frame squarely under the plot frame, unfastening the leashes that hold the plot frame to the anchor cable, and then raising the lifting frame gently with the winch until it clears the water surface. The plot is then allowed to drain for 1 min. (adopted as standard after several trials), and the weight is read directly from the voltmeter display. After being weighed, the plot is lowered gently back into the water until it floats free from the lifting frame, the leashes are refastened to the anchor cables, and the apparatus is then backed gently away to leave the plot frame floating again in its original position.

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REMOTE SENSING OF AQUATIC PLANTS

by

L. E. Link, Jr., and K. S. Long*

BACKGROUND

Efficient control of aquatic plants depends to a large degree on the ability to assess rapidly both their areal extent and their species composition. Decisions concerning the type of control measure to be applied, the magnitude of the application, and the location for application require this information. Currently, an adequate means does not exist at the operational level for rapidly determining the position, extent, and character of aquatic plant infestations over large areas. In addition, the dynamic character of aquatic plant communities requires the ability to examine large areas repetitively, both to identify areas where rapid growth is occurring and to monitor the effectiveness of ongoing control measures.

An important goal of the U. S. Army Engineer Waterways Experiment Station (WES) research efforts in aquatic plant control is the development of an operational capability for mapping the distribution and character of aquatic plants with emphasis on ease of application, rapid execution, and use of available remote sensor systems and technology. The final product of the study will be guidelines for using remote sensors and rapidly extracting and portraying information on aquatic plants.

PROBLEM DEFINITION

Personnel of Corps of Engineers districts and divisions and the WES met at the WES in September 1975 to discuss the informational needs of Corps personnel actively engaged in aquatic plant control at the district level. The results of this fruitful meeting are summarized as follows:

a. The types of information desired would optimally be the areal distribution of the various aquatic plant species and a quantitative categorization of their biomass. If neither species nor biomass could be determined, information concerning the areal distribution of emergent and submersed aquatic plants (without species determination) would be useful for planning control measures.

b. The specific plant species of interest include hydrilla (*Hydrilla verticillata* Royle), Eurasian watermilfoil (*Myriophyllum spicatum* L.) egeria (*Egeria densa* Planch.), waterlettuce (*Pistia stratiotes* L.), waterhyacinth (*Eichhornia crassipes* (Mart) Solms.), duckweed (*Lemna* sp.), waterchestnut (*Trapa natans* L.), and alligatorweed (*Alternanthera philoxeroides* Griseb.).

c. Two scales of information are desired: a regional picture of the distribution and areal extent of aquatic plants for yearly budget planning and analysis, and more frequent detailed information for planning control operations and examining the effectiveness of control measures.

Acquisition of the data outlined above requires the ability to: (a) differentiate aquatic plants from their common surrounds, such as water or terrestrial plants; (b) differentiate from one another the various aquatic plant species; and (c) differentiate, for a given species, variations in plant biomass. Obviously, each successive differentiation is more difficult, especially for submersed aquatic plant

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species. It is also pertinent that these differentiations be made by Corps of Engineers district personnel on a timely basis without additional manpower.

PROPERTIES OF REMOTE SENSOR IMAGERY

In view of the above requirements, it is useful to examine the specific properties of remote sensor imagery that allow an investigator to extract information from an image. These properties can be summarized as spectral properties, pattern properties, and association properties. Spectral properties concern image tones. That is, objects or features with different reflectance or absorption characteristics are portrayed as different gray tones (or colors) on an image. If some prior knowledge is available concerning the relative spectral character of features of interest, tonal variations alone may be used to discriminate among features. This is, of course, the simplest type of information extraction and can be accomplished by visual image interpretation or, in some instances, by automated machine processing. It should be emphasized that this is presently the only type of automated information extraction that is available.

Pattern properties concern regular or irregular groupings of image tones (or colors) or simply tonal "patterns." Tonal patterns are a function of both the spectral properties and the spatial character of the feature (i.e. surface roughness, areal distribution, etc.). This type of information may be exemplified by the regular mottled pattern of a cornfield or the regular pattern of dark tones on a light background of an orchard observed in low-altitude aerial photographs.

Association is the major source of information for visual image interpretation. It relies heavily on the spectral and pattern properties of an image and the knowledge base of the interpreter. Association is poorly understood and can be best defined by an example. A smooth gray area (on an aerial photograph) around a residential building is almost instantly recognized by an interpreter as a lawn, not because it is smooth and gray, but because it is positioned in a certain way with respect to the building. The precise same shade of gray associated with a building identified as a factory might well be interpreted as a parking lot.

For the purposes of developing an easy-to-apply technique for mapping aquatic plants, it would be beneficial if all the desired information could be obtained by spectral properties alone. This would be the simplest procedure and might also allow, to some extent, automation of the information extraction procedure. It is not anticipated, however, that image spectral properties alone will provide all of the desired information previously outlined. For this reason attention must be given to all three image properties, although emphasis should be placed initially on the spectral content of images since it will provide the most immediate return.

SCOPE AND PURPOSE OF STUDY

This paper will present a synopsis of the work that is being accomplished in the Corps Aquatic Plant Control Research Program on the remote sensing of aquatic plants. Work items planned for the future are also discussed.

The initial study efforts have been designed to determine the feasibility of acquiring the desired information for aquatic plants (i.e. location, species, and character) with existing sensor systems that would be available to the Corps districts. The follow-on work will involve formulation of guidelines for applying remote sensors for data acquisition, including setting forth criteria for mission planning,

information extraction, and information portrayal. The final product will be in manual form for efficient technology transfer.

ONGOING INVESTIGATIONS

The work to date has been to determine the feasibility of acquiring information concerning the extent and composition of aquatic plant assemblages by using currently available remote sensing procedures. The following discussion is divided into four sections: a literature review, a description of remote sensing systems, model studies, and field (imagery) investigations.

Literature Review

A literature review was conducted to identify relevant work by other investigators. Scientists at the National Aeronautics and Space Administration (NASA) Kennedy Space Center, Florida, under contract to the Florida Department of Natural Resources, have been investigating the use of aerial photography and interactive image processing to monitor the status of hydrilla in small lakes where white amur fish (*Ctenopharyngodon idella* Val.) have been introduced.[1] Their work has demonstrated the feasibility of accurately delineating and measuring the area of hydrilla infestations with low-altitude aerial photography. Dr. Charles Welby of North Carolina State University at Raleigh used Landsat data in a study for the Corps of Engineers Wilmington District that demonstrated the feasibility of delineating Eurasian watermilfoil infestations in certain North Carolina estuaries.[2] Personnel at the Remote Sensing Center, Texas A&M University, College Station, under the sponsorship of NASA, the Texas Water Quality Board, and the Corps of Engineers, have examined the use of aerial photography for detecting the presence of submersed and emergent aquatic plant infestations in selected locations in Texas.[3] The results of these latter studies showed the feasibility of using color and color-infrared (IR) aerial photography to detect the presence of species such as hydrilla, waterhyacinth, and duckweed. The results obtained by these investigators are being used to support and [illegible] e ongoing WES effort by providing basic data from which additional experiments are design [illegible] supplement the results of the WES studies.

Description of Remote Sensing Systems

Remote sensing systems vary considerably in the types of information they provide. Airborne photographic sensors operate in the "visible" portion of the electromagnetic spectrum and record the energy reflected from the surface of features. The resulting photographs are normally the easiest of all remote sensing products to interpret because the films used have roughly the same sensitivity as the human eye. Thus, the human interpreter is accustomed to what he sees on the photographs. Other sensors, such as the multispectral scanner (MSS) system in Landsat, also record reflected energy and produce photo-like images of the terrain. The major difference is that, in the case of Landsat, the earth's surface is being viewed from space and the resulting resolution is much less than for photos acquired from an aircraft. Landsat provides the advantage of covering large areas in a single scene.

A second type of remote sensing concerns the thermal-IR portion of the electromagnetic spectrum. Thermal-IR systems record the energy radiated from terrain materials. The amount and spectral character of the energy is a function of the temperature and radiation characteristics of the materials. A third major type of remote sensing concerns radar or microwave systems. These systems (called side-looking radar) transmit a pulse of microwave energy to the side of the aircraft (perpendicular to its flight

path) and record the energy backscattered from the terrain surface. The amount of energy returned is a function of the surface roughness of the terrain surface. Side-looking radar systems also allow coverage of large areas in a short period of time.

Aerial photographs and Landsat imagery, because of differences in reflectance characteristics of aquatic plants and their surrounds, are expected to be effective tools for delineating aquatic plant infestations.

Side-looking radar systems may provide a possible tool for regional-type surveys for emergent and floating aquatic plants because of their differences in roughness compared to relatively smooth water surfaces. Thermal-IR sensors are not expected to be very useful. Because of these basic assumptions, aerial photographic, Landsat MSS, and side-looking radar systems are considered to have the most potential for immediate application to the aquatic plant mapping problem, and are, therefore, the remote sensing techniques emphasized in this study.

Model Studies

Although all of the available remote sensing techniques considered in this study have unique advantages, aerial photography is by far the most commonly used and most readily available. Thus, aerial photographs are the most immediately available source of aquatic plant information. The ability to acquire photos at low and high altitudes provides an easy means of obtaining both detailed and more general (regional) information. In aerial photographic techniques a wide variety of film-filter combinations is available, each having unique spectral sensitivities and, thus, potentially capable of recording different types of information. The ability to discriminate on photographs between aquatic plant infestations and their surrounds, aquatic plant species, and variations in species character, such as biomass, depends to a large extent on the existence of tonal (optical density) contrast among these features. The film-filter combinations that provide the most contrast between features to be discriminated are usually the best for the job. Empirical field studies to determine the best film-filter combinations for obtaining specific types of information (based on spectral properties) are prohibitively costly and time-consuming because of the many different film-filter combinations and terrain features (aquatic plant species, surrounds, variations in species character). A computerized mathematical model of the relations between photographic remote sensors and the environment has been developed by the WES[4] to provide a capability for evaluating the performance of different film-filter combinations for acquiring specific types of data. The model was employed to determine the combinations that showed the most potential for discriminating between aquatic plants and their surrounds and between aquatic plant species. The basic scheme of the model is as follows: (a) the spectral reflectance characteristics of the feature (a noxious aquatic plant in this case) and its surround (other aquatic plants or water, etc.) are input to the program; (b) atmospheric conditions, sensor altitude, and other basic parameters are selected (from a spectrum of conditions available), and the model is run; (c) the output of the computer program is a table giving predicted optical density contrast values for the feature and background and for a variety of selected film-filter combinations. An example of the model output is presented in Figure 1. The rightmost column gives the contrast to be expected for the given feature and background for each film-filter combination listed. For single-emulsion films (e.g. film Nos. 2402, 2403, and 2424) the numerical value of the contrast must exceed 0.30 in order for the contrast to be readily detected by the human eye. The model considers each emulsion of multiemulsion films (e.g. Nos. 2448 and 2443) individually. Therefore, the model output includes a contrast value for the cyan (C), yellow (Y), and magenta (M) emulsions of such films. The optical density values for individual emulsions do

Film		Filter		Optical Density Contrast
2402	Plus-X Panchromatic	12	Yellow	0.017221
2403	Tri-X Panchromatic	12		0.013127
2402		47B	Blue	0.178659
2403		47B		0.164144
2402		58	Green	0.079427
2403		58		0.079427
2402		25A	Red	0.032514
2403		25A		0.014665
2402		3	Haze	0.063758
2403		3		0.043076
2448C	Color*	3		0.000578
2448Y		3		0.270419
2448M		3		0.104692
2443C	Color-IR*	3		0.069592
2443Y		3		0.117260
2443M		3		0.010083
2443C		12		0.146050
2443Y		12		0.067922
2443M		12		0.004641
2424	Black-and-white IR	12		0.194452
2424		25A		0.202076
2424		87C	Infrared	0.173644
2424		87B	Infrared	0.213561

LEGEND

Feature: waterhyacinth, Black Creek, Florida
Background: spatterdock, Black Creek, Florida
Atmosphere: midlatitude, summer, haze: 23 km
Zenith angle: 30 deg
Distance to sensor: 1.50 km

* C, Y, and M represent the cyan, yellow, and magenta emulsions, respectively, for multiple-emulsion color and color-IR film.

Figure 1. Example of model output

not give a true measure of the total contrast that occurs on these films for a feature and background. Thus, some combination of values is necessary. For the purposes of this study, a simple sum of the three (for the three emulsions) predicted optical density values was considered as an approximate value for the total optical density contrast that would occur for the multiemulsion films. The sum of the predicted contrast values was compared with the 0.30 threshold previously mentioned to assess the ability of multiemulsion films to discriminate specific feature-background combinations.

Spectral reflectance curves (for features and backgrounds) are the only input required for execution of the model. For this study spectral reflectance curves of common aquatic plant species and water bodies were obtained in selected locations in New York, Florida, Louisiana, and Texas during the late

summer of 1975. Some additional data were obtained in Louisiana, South Carolina, and Mississippi during the summer of 1976. Figure 2 presents an example of the reflectance values acquired for spatterdock and waterhyacinth. A list of those aquatic plant species and other features associated with them (e.g. water) for which reflectance data have been collected is given in Table 1. These data were used to execute the computer model previously described. Species were compared to every other prominent species associated with them, as well as to the surrounding water.

The specific objective of the model studies was to make an initial assessment of the ability of available photographic film-filter combinations for discriminating (a) areas with submersed aquatic plant infestations from areas with no submersed aquatic plants, (b) areas with emergent aquatic plants from surrounding water, (c) specific submersed aquatic plant species from one another, and (d) specific emergent aquatic plant species from one another. It must be recognized at this point that the ability to detect the presence of submersed plant infestations is very dependent on water clarity. It is logical to assume that in very turbid water, it would be difficult to detect the presence of plants only a few centimetres below the water surface; whereas in clear water, it may be possible to detect infestations at much greater depths. The data represent relatively clear water conditions and, as such, should not be assumed to represent turbid water where the adequacy of specific film-filter combinations to detect submersed plants could decrease significantly. Table 2 presents a comprehensive tabular summary of the results of the model study. The following paragraphs present a brief narrative of the data presented in the table.

Examination of the predicted optical density values for water bodies (for relatively clear water conditions) and specific submersed aquatic plant species shows that species such as hydrilla, egeria, and coontail (*Ceratophyllum demersum* L.) can be readily discriminated from areas of water not occupied by submersed plants. The best film-filter combinations were black-and-white infrared film with yellow, red, or infrared filters and color-IR film with a yellow filter. The predicted optical density values were, for the most part, well above the 0.30 threshold previously mentioned.

Examination of the predicted optical density values for water bodies and specific emergent aquatic plant species shows that species such as waterhyacinth, pickerelweed (*Pontederia* sp.) and frogbit (*Limnobium Spongia* (Bosc) Steud.) can be easily discriminated from water bodies using black-and-white infrared film with yellow, red, or infrared filters, color-IR film with a yellow filter, and, in most cases, color film with a haze filter. In some instances other film-filter combinations were also adequate (i.e. provided a contrast greater than 0.30); however, the above combinations were the most consistent.

Examination of the predicted optical density contrast values for combinations of specific submersed aquatic plant species shows that it does not appear to be feasible to discriminate between hydrilla and egeria on aerial photographs.

Examination of the predicted optical density contrast values between specific emergent (or floating) aquatic plant species shows that, in some instances, waterlettuce and *Salvinia* sp. with duckweed, duckweed and American lotus (*Nelumbo lutea* (Willd.) Pers.), American lotus and yellow waterlily (*Nuphar* sp.), frogbit and yellow waterlily, and American lotus and *Panicum*, there was not sufficient optical density contrast to allow visual discrimination on aerial photography. On the other hand, the predicted optical density values for combinations such as waterfern (*Azolla* sp.) and waterhyacinth, waterhyacinth and *Vallisneria* sp., frogbit and *Panicum*, and waterhyacinth and spatterdock (*Nuphar* sp.), indicate that they could be discriminated from one another. Black-and-white infrared film with yellow, red, and infrared filters and color-IR film with a yellow filter appear best for the above discriminations; color film with a haze filter was marginally adequate for discrimination in

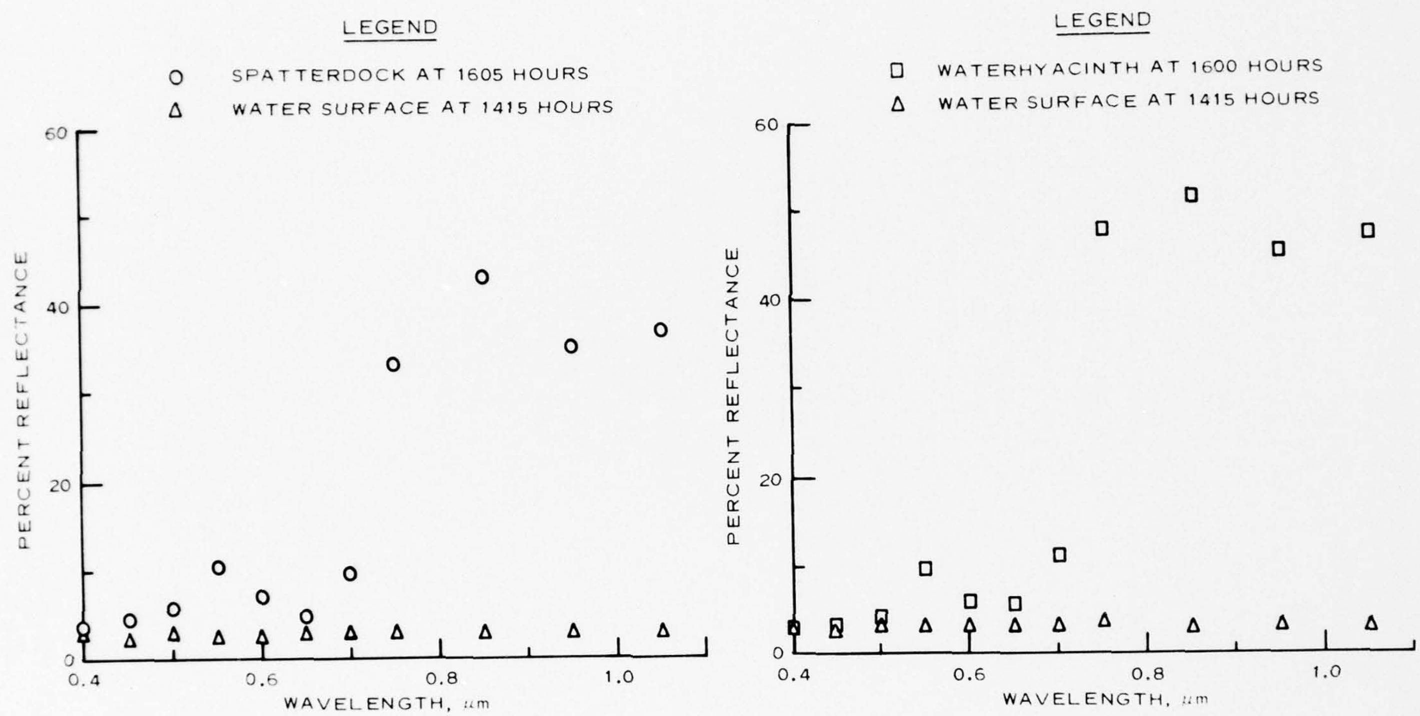


Figure 2. Reflectance curves for waterhyacinth and spatterdock

Table 1
Aquatic Plants from Which Spectral Reflectance Data Were Collected

Date	Location	Organism/Feature
September 1975	Florida	Waterhyacinth, alligatorweed, frogbit, waterfern, tapegrass, pickerelweed, hydrilla, pennywort, green algae, cattails, water paspalum, Eurasian watermilfoil, salvinia, spatterdock, waterlettuce, egeria, associated water
September 1975	New York	Waterchestnut, associated water
September 1975	Louisiana	Waterhyacinth, coontail, cabomba, hydrilla, associated water
October 1975	Texas	Waterhyacinth, alligatorweed, associated water
July 1976	South Carolina	Egeria, waterprimrose, waterlily, associated water
September 1976	Louisiana	Waterhyacinth (living and dead), American lotus, egeria, frogbit, duckweed, hydrilla, Eurasian watermilfoil, panicum, associated water

some cases (e.g. waterhyacinth and spatterdock, and frogbit and *Panicum*).

The results of the model studies suggest that in almost all instances (in clear water conditions), it appears feasible to detect the presence of both submersed and emergent aquatic plant infestations with readily available film-filter combinations. In some instances specific comparisons of certain species do not appear to create an optical density contrast of sufficient magnitude to allow discrimination of one species from another. However, there are also instances when available film-filter combinations appear to be quite capable of allowing discrimination among certain aquatic plant species, especially emergent or floating ones.

The ability to discriminate among plant species based on image tone does not necessarily imply the ability to identify a specific plant species without some additional information, such as a prior knowledge of possible species for a given water body or growth patterns of a particular plant. Clearly, attributes of plants other than spectral properties must be considered, namely pattern and associative properties. These properties are more difficult to quantify than spectral properties since they are more a subjective impression than an easily measurable entity.

Field Studies

To confirm the model predictions and to establish further the ability to acquire information on aquatic plant species extent and composition with aerial photography, a number of field studies were initiated. The field studies consisted of acquiring ground truth data and aerial photographs of selected water bodies having infestations of a variety of aquatic plant species. Table 3 lists the water bodies selected and important aquatic macrophytes in each. The field studies were initiated with the acquisition of ground truth data and aerial photography at Lake Boeuf, Louisiana, in May 1976; Lake Theriot, Louisiana, in May 1976; and Ross Barnett Reservoir, Mississippi, in April 1976. Ground truth data and photographs were obtained at Santee-Cooper Reservoir (Lake Marion), South Carolina, in July 1976. The aerial photographs were obtained from light aircraft with hand-held 35 and 70mm cameras. The film-filter combinations used were based primarily on the results of the model studies and are listed in Table 4. A second ground truth and air-photo survey was accomplished at Lake Boeuf, Louisiana, Lake

Table 2
Tabular Summary of Results of Model Studies

	Water	Waterhyacinth	Frogbit	Waterfern	*Vallisneria*	*Hydrilla*	Coontail	*Egeria*	Pickerelweed	Waterlettuce	Salvinia with Duckweed	Alligatorweed	Spatterdock	Duckweed	American lotus	*Panicum*	Naiad	Waterprimrose	Cabomba
Water		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Waterhyacinth			X M	X	X	X		X	M	X		X	X M	X	X	X			
Frogbit													O	X	X	M			
Waterfern																			
Vallisneria																			
Hydrilla							M	O											
Coontail																			M
Egeria																	X	X	M
Pickerelweed																			
Waterlettuce											O	M							
Salvinia with duckweed												M							
Alligatorweed																			
Spatterdock														X	O	M	X	X	
Duckweed														X	O	M	X	X	
American Lotus																O			
Panicum																			
Naiad																		X	
Waterprimrose																			
Cabomba																			

Note: Blank = comparison not made; X = discrimination possible with at least one of the film types considered; M = discrimination marginal; and O = discrimination not possible.

Table 3
Remote Sensing of Aquatic Plants, Field Study Sites

Location	Mean Depth m	Area km²	Important Aquatic Macrophytes
Lake Boeuf, Louisiana	1.0 to 1.5	7.0	Waterhyacinth, *Egeria*, duckweed, watermeal, American lotus, white waterlily, yellow waterlily, frogbit, *Panicum*
Lake Theriot, Louisiana	1.0 to 1.5	5.2	*Hydrilla*, waterhyacinth, Eurasian watermilfoil, yellow waterlily
Ross Barnett Reservoir, Mississippi	3.7	121.5	Naiad, pondweed, watershield, American lotus, coontail
Lake Marion, South Carolina	6.7	447.6	*Egeria*, waterprimrose, naiad

Theriot, Louisiana, and Ross Barnett Reservoir, Mississippi, in September 1976 to examine late-season or mature-growth-stage conditions. A full-coverage air-photo mission of the Santee-Cooper Reservoir was designed and a request made to the Aviation Division, Georgia Army National Guard, to execute the mission during the month of October 1976. A mission covering the upper portion of Lake Marion at a scale of 1:10,000 was flown on 18 November 1976, but these photographs have not yet been received and analyzed.

In addition to the detailed work conducted at the three test water-bodies, high-altitude (acquired at a scale of 1:120,000 with a U-2 aircraft) aerial photographs and Landsat imagery have also been acquired. These images are being used to determine the relative quantity of information available on high-altitude imagery with respect to the information available on the low-altitude, detailed photos. It is envisioned that high-altitude photographs or Landsat imagery may provide a viable means of surveying large areas although the information obtained will be less specific than that available on low-altitude photos.

Figure 3 shows examples of the low-altitude aerial photographs of Lake Theriot, Louisiana, obtained in the field studies. Features evident on the photos are a canal entering the lake (near the top of each photo), an area of marsh vegetation (upper half of each photo), and an area of water heavily infested with hydrilla with some local infestation of waterhyacinths (lower portion of each photo).

Examination of the photographs in Figure 3 shows that the color-IR film with a yellow filter (Figure 3a) produced the best discrimination of the submersed hydrilla from areas with no hydrilla (mainly the canal and its extension into the lake) and the rafts of waterhyacinth. The color film (Figure 3b) shows the rafts and fringe areas of waterhyacinths very well, but does not produce much contrast between the hydrilla-infested areas and the open-water areas, although the hydrilla is detectable. The black-and-white infrared film (Figure 3c) was underexposed but did produce good contrast between the hydrilla-infested areas and open water. The waterhyacinth rafts are detectable on the image but not as well as on the color-IR and color images (Figures 3b and 3c, respectively). The panchromatic film with a red filter (3d) shows little contrast between the hydrilla-infested areas and the open-water areas; the areas of waterhyacinth were readily apparent. Of the four film-filter combinations shown, optical densities of (a) 1.04, (b) 0.81, (c) 0.85, and (d) 0.46, respectively, were predicted for hydrilla versus

Table 4
Film-Filter Combinations Used at Each Study Site

Location	Date	Camera	Film	Filter(s)
Lake Boeuf, Louisiana	15 May 76	Hasselblad	Color-IR	12
			Panchromatic	47
				58
				25
			Color	--
		Alpa	Black-and-white IR	12
				25
			Color-IR	12
	17 September 76	Alpa	Black-and-white IR	--
				Pol*
				25
			Color-IR	Pol
				12
			Plus-X Pan	Pol
				12
				25
				--
			Ektachrome-X	--
Lake Theriot, Louisiana	15 May 76	Hasselblad	Tri-X	47
				58
	17 September 76	Alpa	Black-and-white IR	--
				Pol
				25
			Color-IR	Pol
				12
			Kodacolor II	--
			Plus-X Pan	Pol
				12
				25
			Ektachrome-X	--
Ross Barnett Reservoir, Mississippi	21 April 76	Hasselblad	Color-IR	12
				47
				58
			Plus-X	12
				25
				--
		Alpa	Kodacolor II	--
			Plus-X Pan	12
				25
				--
			Ektachrome-X	--

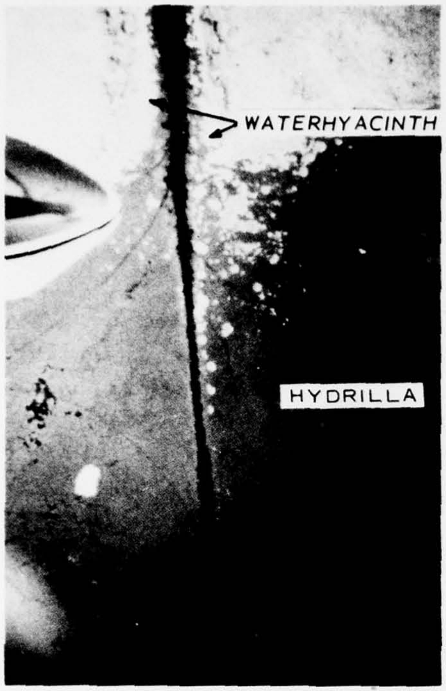
(Continued)

* Polarizing.

Table 4 (Concluded)

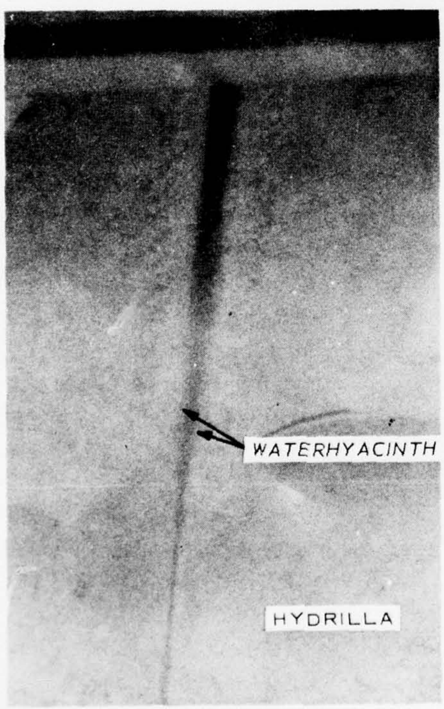
Location	Date	Camera	Film	Filter(s)
Ross Barnett Reservoir, Mississippi	10 September 76	Alpa	Plus-X	Pol*
				Pol + 12
				Pol + 25
			Color-IR	Pol
				Pol + 12
				12
			Black-and-white IR	--
				Pol
				Pol + 25
				25
			Ektachrome-X	--
			Kodacolor II	--
Lake Marion, South Carolina	21 July 76	Alpa	Black-and-white IR	Pol
				Pol + 25
				--
				25
			Plus-X Pan	Pol
				Pol + 12
				Pol + 25
			Ektachrome-X	--
			Color-IR	Pol
				Pol + 12
				12
	18 November 76	Color	Haze	
			Color-IR	12

* Polarizing.

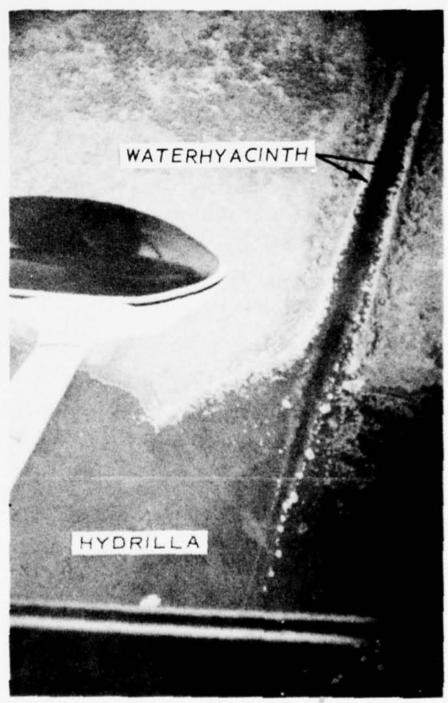


a. Color IR with yellow (Wratten 12) filter

b. Color



c. Black-and-white infrared



d. Panchromatic with red (Wratten 25) filter

Figure 3. Low-altitude (c. 1000 ft) aerial photographs of a portion of Lake Theriot

waterhyacinth. These relative values are not inconsistent with the subjective evaluation of the photographs, except for the relative ranking of the black-and-white infrared (c) and the Plus-X panchromatic film (d). The optical density contrast values predicted for the film-filter combinations shown for hydrilla and its surrounding water were (a) 0.41, (b) 0.16, (c) 0.68, and (d) 0.05. Again, the relative order of contrast agrees with predictions with respect to the color-IR and color films.

The ground truth data and low-altitude photographs at Lake Boeuf, Louisiana, revealed that the areas of waterhyacinths and the areas of duckweed were easily distinguished from each other on color-IR (with yellow filter), black-and-white infrared (with red filter), and color photographs. Contrasts between duckweed and waterhyacinths predicted by the model using reflectance data obtained in 1976 were shown to be, in order of decreasing contrast values, color (1.69), color-IR with a Wratten 12 filter (0.99), color-IR with a haze filter (0.95), panchromatic with a Wratten 58 filter (0.57), panchromatic with no filter (0.46), and black-and-white infrared with an 87C filter (0.40). Because the waterhyacinth and duckweed populations at times covered the water surface, the areas of submersed plants (mostly egeria) were not always detectable. The waterhyacinth infestations had an obvious cloning pattern that resembled the patterns of cloning seen in molds and bacteria growing on agar plates. On reflection this analogy is probably not too inappropriate, for the processes producing the two phenomena are quite similar even though the scale is different. The similarity exists probably because reproduction of introduced aquatics is almost totally vegetative, resulting in a spread outward from a central locus. The similarity between molds and bacteria on an agar plate and plants growing in an aquatic environment is particularly striking in low-altitude photography (1000-2000 ft). Time has not been sufficient to examine all of the images in detail for pattern characteristics, but the evidence to date indicates that growth patterns may be helpful for identification of some species.

Examination of the low-altitude aerial photographs at Ross Barnett Reservoir, Mississippi, revealed that color-IR (with a yellow filter) photographs best showed areas of submersed naiad (*Najas* sp.). The black-and-white infrared film with a red filter also allowed identification of naiad infestations. Though no radiometric measurements were taken of the submerged naiad at Ross Barnett, a similar species was measured at Lake Marion, South Carolina. Using these data, the model predicted best contrast with color-IR film with a Wratten 12 filter (0.72), followed by color-IR film with a haze filter. The model predicted adequate contrasts with other film-filter combinations as well—black-and-white infrared with an 89B filter (0.71) and color film with a haze filter (0.63). The presence of watershield, a floating-leaved plant, was easily detected on color film as well as on color-IR film.

Examination of the low-altitude photographs of the Santee-Cooper complex revealed that color-IR film with a yellow filter gave excellent discrimination among areas of submersed egeria, areas of waterprimrose (*Ludwigia uruguayensis* Camb.), and uninfested water areas. Color photographs also allowed easy discrimination of waterprimrose (from water) and some identification of areas of egeria. Black-and-white infrared film with a red filter also provided good discrimination of areas of egeria from water as well as from areas of waterprimrose. The model predicted the following film-filter combinations to yield detectable contrast between egeria and waterprimrose, based on reflectance data collected at Santee-Cooper within 2 days of photographing the test sites, in order of decreasing contrast: color film with a haze filter, black-and-white infrared film with an 87C filter, color-IR with a yellow filter, and color-IR with a haze filter.

The results of the low-altitude aerial photography examinations are consistent with the results of the model studies and demonstrate the ability of commonly available photographic systems to obtain information concerning the extent and composition of aquatic plant infestations. For example, the

results of the model studies summarized in Table 2 show that each of the organisms for which spectral reflectance characteristics were analyzed could be distinguished from its surrounding water by one or more of the film-filter combinations considered. Field exercises supported this prediction. Similarly, waterhyacinths when photographed with duckweed contrasted markedly in tone, whereas tone discrimination between waterhyacinth and spatterdock was not nearly as distinct. The field results, in summary, essentially agreed with model results in relative intensity of contrast.

Figure 4 shows an enlargement of a portion of a color-IR high-altitude aerial photograph of Lake Boeuf, Louisiana. The photograph represents conditions in October 1974, when significant infestations of numerous species (egeria, waterhyacinth, and duckweed) had occurred. The presence of aquatic plants is easily detected on this image. Cursory examination of high-altitude color-IR aerial photographs for Lake Theriot (Figure 5) revealed an ability to detect Eurasian watermilfoil infestations, and imagery of Ross Barnett Reservoir (Figure 6) showed the ability to detect watershield (*Brasenia Schreberi* Gmel.) infestations.

Figure 7 shows a photographic enlargement of a band-7 (near-IR) Landsat image of the upper portion of Ross Barnett Reservoir in April 1976. Comparison of this image with ground truth data for the same time reveals that areas of watershield appear to be evident on the image. Landsat band-7 imagery of Lake Boeuf, Louisiana (Figure 8), shows obvious evidence of aquatic plant infestations exhibiting many image tones, indicating a possible ability to obtain additional information. Additional

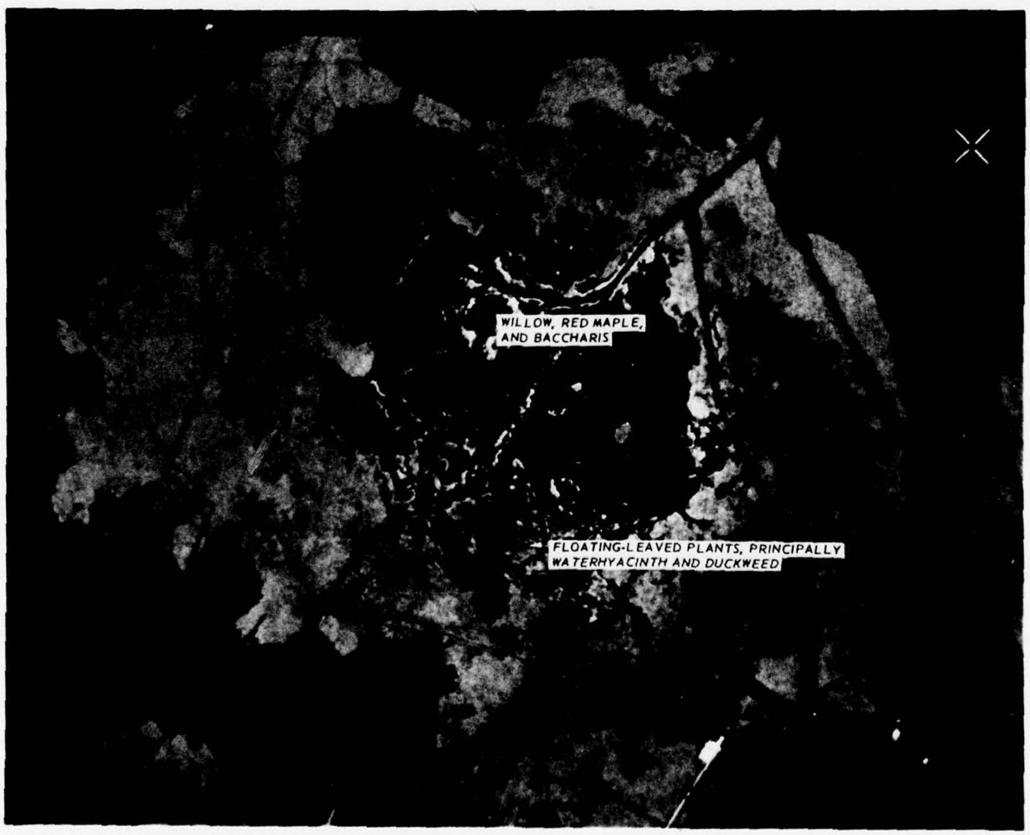


Figure 4. Color-IR high-altitude (c. 60,000 ft) photographs of Lake Boeuf, Louisiana

Figure 5. Black-and-white infrared high-altitude (c. 60,000 ft) photographs of Lake Theriot, Louisiana

work will be performed with the Landsat images in digital format to define the information available on Landsat imagery.

FUTURE STUDY EFFORTS

Presently, much emphasis is being placed on detailed interpretation and analyses of the different types of imagery acquired from the field studies. A careful comparison will be made among the spectral, spatial, and associative properties of the individual images and the associated ground truth information. The results of this effort will be a definition of the information gathering capability of each sensor type (i.e. to obtain information concerning the composition and extent of aquatic plant infestations) both for detailed and regional scale information.

Side-looking radar was mentioned previously as a potential regional survey tool. A radar imaging mission of the Withlacoochee River Basin, Florida (including Rodman Reservoir), and the area from Lake Apopka to Orlando, Florida, has been planned; a request for its execution has been submitted to

Figure 6. Color-IR high-altitude (c. 60,000 ft) photographs of Ross Barnett Reservoir, Mississippi

the 363rd Tactical Reconnaissance Wing, U. S. Air Force Tactical Air Command, Shaw Air Force Base, South Carolina. The side-looking radar imagery will be obtained with the AN/APQ 102 synthetic aperture system that covers a ground swath of approximately 20 miles for each flight path and has a resolution of approximately 50 ft. A previous study conducted for NASA by the Environmental Research Institute of Michigan demonstrated the feasibility of observing large areas of floating aquatic plants using a very sophisticated and experimental radar system. The U. S. Air Force System is a more operations-oriented system in that it has been used for many years as the standard radar imaging system for Air Force reconnaissance missions. High-altitude aerial photographs of the study areas will be obtained to aid in evaluation of the aquatic plant information available on the side-looking radar imagery.

The aerial photography obtained for the Santee-Cooper Reservoir System will be used as an example of a large-scale field test for using aerial photographs to determine the extent and composition of aquatic plant infestations in a large water body (360 square miles). The photographs will be interpreted to delineate areas inhabited by individual (major) plant species and the results field checked for verification. A second aerial-photograph mission over the Santee-Cooper complex is scheduled for the spring of 1977.

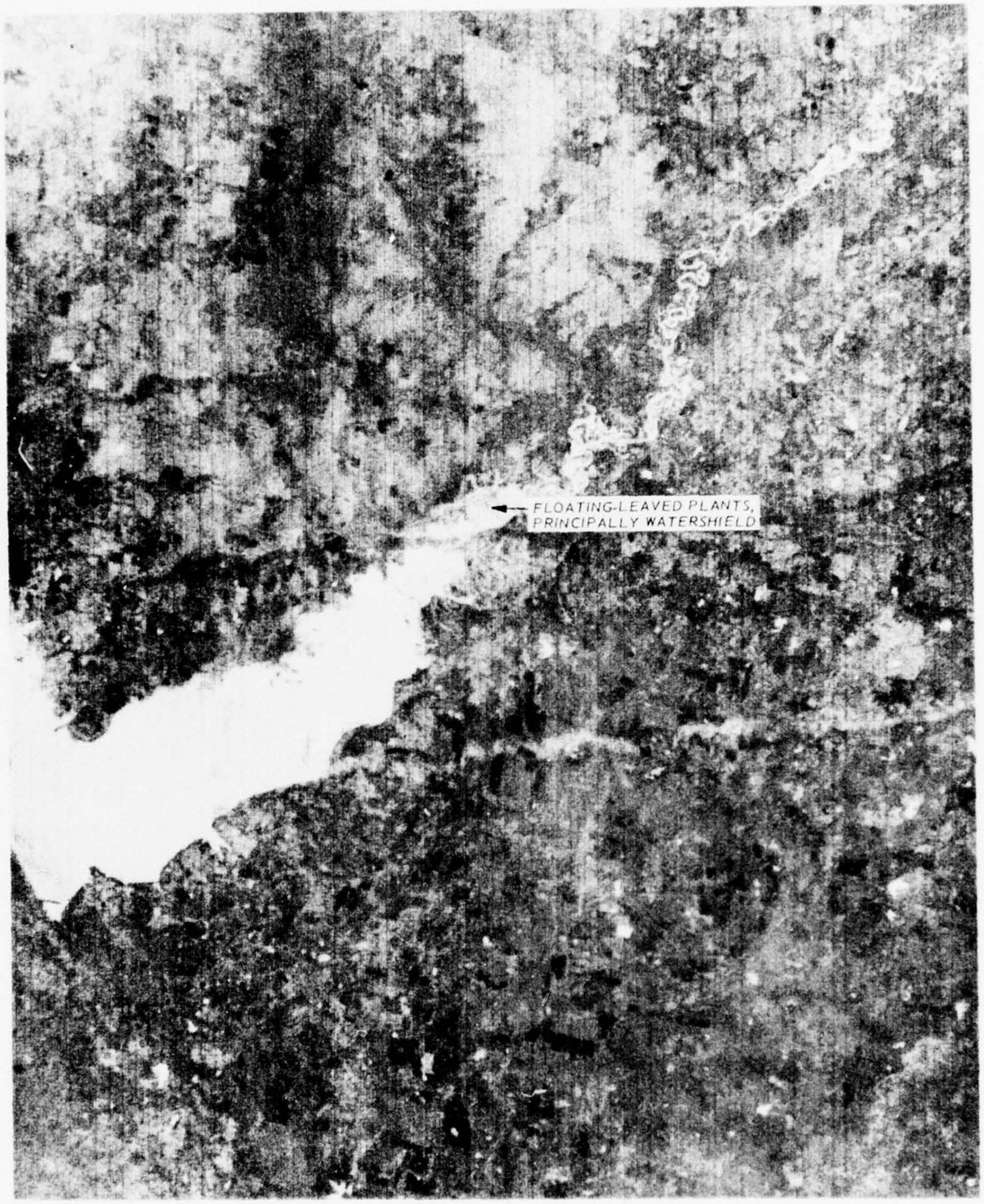


Figure 7. Portion of Landsat band-7 image of Ross Barnett Reservoir, Mississippi (10 April 1976)

Figure 8. Enlargement of Landsat band-7 image of Lake Boeuf, Louisiana (16 May 1976)

The follow-on work involves the design and implementation of an effective procedure for Corps district personnel to acquire rapidly needed information concerning the extent and composition of aquatic plant infestations via available remote sensor technology. This may involve development of some automated interpretation procedures for use with high-altitude and satellite imagery for rapid surveillance of very large areas and detection of potential problem areas. In addition, the relative costs of the available procedures and the resources necessary for their implementation will be examined. It is envisioned that several large-scale field programs, such as that described for the Santee-Cooper complex, will be planned and implemented to gain practical insight into effectiveness of the techniques, to identify items requiring additional development, and to effect a technology transfer to potential users.

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DATA MANAGEMENT SYSTEMS IN THE AQUATIC PLANT CONTROL RESEARCH PROGRAM

by

J. A. Parks*

The key to research is data, and the degree of success associated with that research depends largely upon the quality, quantity, and form of these data. It is important, therefore, that the management of the data be performed as an organized, efficient operation requiring a minimum amount of effort. In the Aquatic Plant Control Research Program, we are designing and implementing the use of data management systems that are simple enough to describe and explain easily, but complex enough to contribute sufficiently to the solution of a whole spectrum of aquatic plant control related problems, both immediate and long-range.

The design and development of a data management system that will serve as an effective instrument in conducting any research begins in the preliminary stages of the establishment of the project, since such a system is a cooperative effort of personnel involved in all levels toward the completion of a specific research endeavor.

There are three elements in any data management system. Each is a separate entity; however, all are interrelated and dependent to some extent upon one another. The first of these is data collection, the initial introduction of the data to the system. This area is primarily the responsibility of the scientists and technicians who set guidelines about what data are to be measured, what sampling procedures are to be used, and what degree of precision is necessary to effect reliability and validity in the data and in recommendations resulting from the data. Overlapping part of this area is the second element, data storage, which is the responsibility of the data coordinator, who works out of the Waterways Experiment Station (WES) office. Included in this element are such tasks as designing and furnishing forms and formats for the data collection, performing necessary editing operations, filing, cataloging, making decisions pertinent to storage media, acting as controlling and coordinating center, and attending to related tasks. As a result of the first two elements, the third element, data retrieval and display, exists. The data coordinator communicates with the "user" of the data and supplies whatever is necessary to help him get his job done. This may take a variety of forms, a few of which are graphs, maps, charts, tables, and data in a form to be used as input to other computer activities.

These three elements serve as an outline of the progressive movement of data from the source (i.e. field sampling, literature search, etc.) to the hands of those people who analyze, manipulate, and examine them before drawing conclusions, formulating solutions, and providing operations with methods to set about controlling aquatic plant problems.

To devise and maintain a workable data management system, five valuable components should be considered:

a. Precision

b. Correct form

c. Completeness

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d. Timeliness (scheduling)

e. Sufficient identification for adequate reference and cross-reference demands

Presently, there are four research efforts in progress under the guidance of the Aquatic Plant Control Research Program, and each requires its own data management system. Because the efforts are very diverse in plan and purpose, a unique system for each must be designed based upon the individual specifications determined by the characteristics and requirements of that particular effort.

DATA MANAGEMENT SYSTEM FOR LAKE CONWAY TEST

The Large-Scale Operations Management Test being conducted at Lake Conway, Florida, is a project that offers the opportunity for developing a data management system characterized by the ability to respond to requests and demands for data from innumerable sources, and simultaneously provide valuable information pertinent to the solution of a particular aquatic plant problem. In dealing with a project of this size in terms of data storage and retrieval, it is imperative that the initial step is to establish strong lines of communication among the contractors, data coordinator, and users of the data. Once this is accomplished, the design of the system can be set in motion.

Figure 1 shows a diagram of the basic flow of the data through the system designed for the test at Lake Conway. Field data forms have been designed for each type of data and are in the process of being tested, refined, and improved in the actual data collection environment. Completed forms are sent to the coordinator who performs some basic editing on them before having them punched into computer cards. The punched cards are input to the computer where programs and routines do further editing and then store the data in the appropriate file where they reside until needed. As requests are made, the

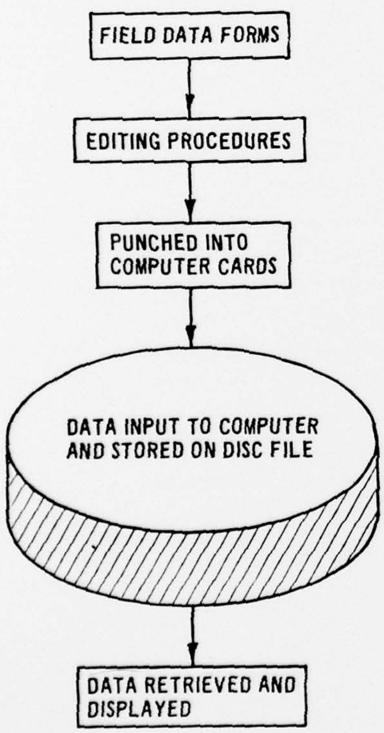

Figure 1. Diagram of basic flow of data through the system for the Large-Scale Operations Management Test

DATA CATEGORIES

WATER QUALITY
SEDIMENT QUALITY
ZOOPLANKTON
PHYTOPLANKTON
BENTHIC INVERTEBRATES
PERIPHYTON
FISH
WATERFOWL AND BIRDS
MAMMALS
AQUATIC VASCULAR PLANTS

Figure 2. Data categories for the Large-Scale Operations Management Test

retrieval system is put in operation, and data are output according to specific requests of the user.

Figure 1 tends to leave the impression that the entire procedure is quite simple, when actually it is a complex mechanism incorporating several data sources, multiple computer programs and specialized techniques, and a large number of personnel moving in many different directions. To fully realize how intricate the system is, several members of the diagram can be examined singularly.

Field data forms are designed for each category of data (Figure 2); these categories were established in the planning stage of the test and prevail throughout the data system. Figures 3-5 show the sheets that comprise the data forms for zooplankton. This same basic design is used for all categories; but parameters, size of values, and number of items required effect differences in the forms' appearances. These designs are the result of discussions, exchange of ideas, and sometimes compromise between those involved in data collection and those in data storage and retrieval.

As the forms are received by the data coordinator, there are some minor editing tasks that are performed. These are very simple procedures, such as checking to see the form is the correct one and if all the sheets are present, checking legibility, being sure all data are numeric, etc., and do not directly involve the data values. From this editing, the forms are submitted for key punching; and after the cards are completed, sorted, and given a final check, they are input to the computer.

The procedures for storage are separate computer routines, one for each data category. These routines sort, select, and store in a predetermined file the data contained on these cards, and these data remain in this position until called out. Successive sets of data in the same category are stored one after another on a removable disc file, creating a useful data base. At present there is one removable disc dedicated to the Conway project, which represents available storage for 24,883,200 characters.

Retrieving items of information from the data base is not a complicated process, but to make available a wide selection for displaying the output and results, a number of computer routines and programs are required (Figure 6). There are decisions about the most effective means of presentation, and there is quite a lot of time and effort dedicated to planning and programming so that the user receives a product as quickly and efficiently and in as great a quantity as satisfies him.

DATA MANAGEMENT SYSTEM FOR LAKE CONCORDIA TEST

A research effort oriented in a different direction is the test being conducted using several biological controls on waterhyacinths at Lake Concordia, Louisiana. The scope of this test is very limited and

Page ___ of ___

DATA FORM FOR MICROORGANISMS

ZOOPLANKTON

Project Name: ______________________

Investigator: ______________________

Location: ______________________

Date: ______________________

Field Personnel: ______________________

Sample No.	Factor	Date				Site		Coordinates		Time		Sample Depth		Sampling Method			Sheet No.
		Code	YR	MON	DAY	Code	Value	Code	Value	Code	Value	Code	Value	Code	Value		
1 2 3 4	5 6	7 8 9 10	11 12	13 14	15 16	17 18 19 20	21 22 23 24 25 26	27 28 29 30	31 32 33 34 35 36	37 38 39 40	41 42 43 44	45 46 47 48	49 50 51 52 53 54	55 56 57 58	59 60 61 62 63 64	65 66 67 68 69 70 71 72 73 74 75 76 77 78	79 80
	7	0 0 0 1				0 0 0 2		0 0 0 3		0 0 0 4		0 0 0 5		0 0 0 8			1
	7																1
	7																1
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Figure 3. Sheet 1 of zooplankton data form for the Large-Scale Operations Management Test

DATA FORM FOR MICROORGANISMS

ZOOPLANKTON

Page ___ of ___

Project Name: ____________

Investigator: ____________

Location: ____________

Date: ____________

Field Personnel: ____________

Sample No.	Factor	Total Units		Total Units/m^2		Total Units/m^3		Species		Units/m^2		Units/m^3			Sheet No.
		Code	Value	Code	Value	Code	Value	Code	Value	Code	Value	Code	Value		
1 2 3 4	5 6	7 8 9 10	11 12 13 14 15 16 17	18 19 20 21	22 23 24 25 26 27 28	29 30 31 32	33 34 35 36 37 38 39	40 41 42 43	44 45 46 47 48 49 50	51 52 53 54	55 56 57 58 59 60 61	62 63 64 65	66 67 68 69 70 71 72	73 74 75 76 77 78	79 80
	7	2 0 6 0		2 0 6 3		2 0 6 4		2 0 0 0		2 0 1 0		2 0 2 0			2
	7														2
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Figure 4. Sheet 2 of zooplankton data form for the Large-Scale Operations Management Test

Page ___ of ___

DATA FORM FOR MICROORGANISMS

ZOOPLANKTON

Project Name: ____________________

Investigator: ____________________

Location: ____________________

Date: ____________________

Field Personnel: ____________________

Sample No.	Factor	Species Code	Species Value	Units/m² Code	Units/m² Value	Units/m³ Code	Units/m³ Value	Species Code	Species Value	Units/m² Code	Units/m² Value	Units/m³ Code	Units/m³ Value		Sheet No.
1 2 3 4	5 6	7 8 9 10	11 12 13 14 15 16 17	18 19 20 21	22 23 24 25 26 27 28	29 30 31 32	33 34 35 36 37 38 39	40 41 42 43	44 45 46 47 48 49 50	51 52 53 54	55 56 57 58 59 60 61	62 63 64 65	66 67 68 69 70 71 72	73 74 75 76 77 78	79 80
	7	2000		2010		2020		2000		2010		2020			3
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Figure 5. Sheet 3 of zooplankton data form for the Large-Scale Operations Management Test

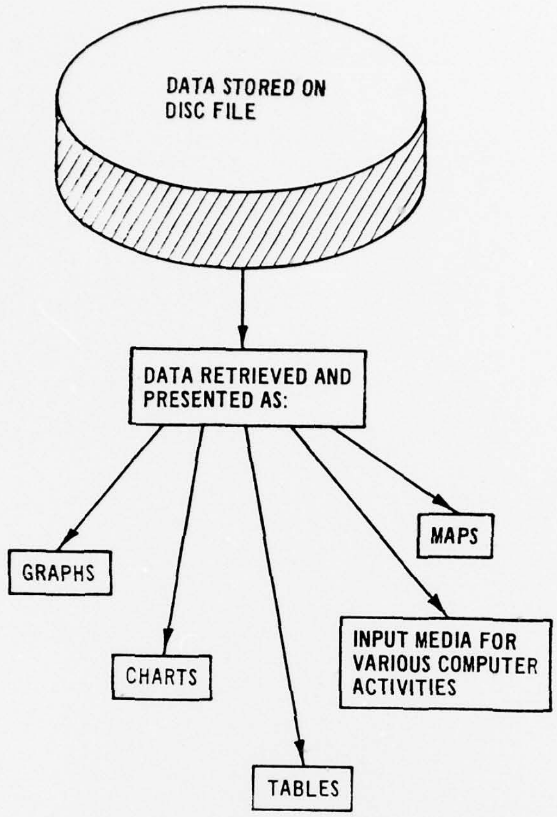

Figure 6. Flow diagram of logic for retrieving and displaying data

demands a management of data not nearly as complex as that at Lake Conway. A simple diagram depicting the flow of data through this system is shown in Figure 7. Data are measured, recorded, and edited by the technicians at the field site, and are then transferred to data forms compatible with computer card punching techniques. After cards have been punched from these forms, the cards are input to the computer where the data are stored in a file, easily accessible at any time through the time-sharing mode using teletypes and remote terminals.

In this test, the types and number of data items sampled are limited and so far have been used primarily for graphic presentations and as input to standard statistical routines kept in the computer-user library. However, there are numerous other methods and means available to present these data using computer programs, some already written and operable, others to be written, expressing specialized use of the data.

WHITE AMUR STOCKING RATE MODEL

The conception and development of the stocking rate model were the result of a need of the test at Lake Conway for computing the number of white amur that should be stocked in the lake to attain a

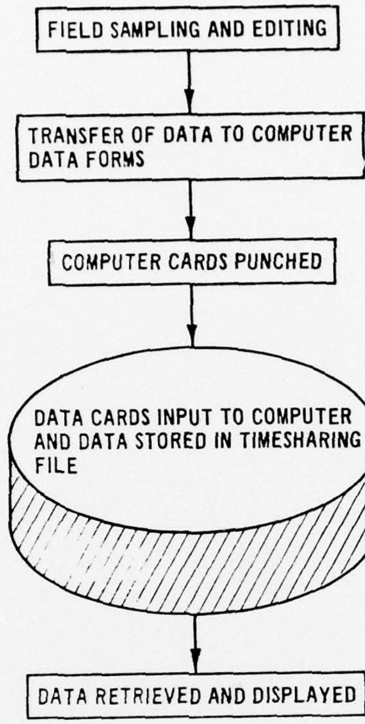

Figure 7. Diagram of data flow through the system for test conducted at Lake Concordia, Louisiana

designated level of control of hydrilla without disrupting to any dangerous extent the equilibrium of the ecosystem present and to accomplish this within some predetermined length of time.

Data management plays a two-phased role with respect to this research effort. On the one hand, there are data to be used as input to the formulation of the model and to the establishment of the initial conditions prior to stocking; whereas on the other hand, there are data to be produced and output in a variety of forms as a result of the calculations in the model.

Figure 8 is a diagram of the logic of the model. It is comprised of six relations and the interrelations of these. Data are needed to verify and suggest modification for these basic relations as well as to establish the existing conditions of the lake's environment.

Graphic presentation of the time history of what effects the fish have on the amount of plant biomass in the lake is an effective method for reviewing the output of this model. The graph in Figure 9 is an example of one segment of a data set output by a single run of the model. From this example the user can derive trends, perform comparisons with similar data sets, and put together a complete picture of several related segments.

DATA MANAGEMENT FOR MECHANICAL HARVESTING

A final area of research requiring its own specialized type of data management is that involving harvesting aquatic plants with mechanical devices. The Aqua-Trio system is a means of aquatic plant

WHITE AMUR STOCKING RATE MODEL

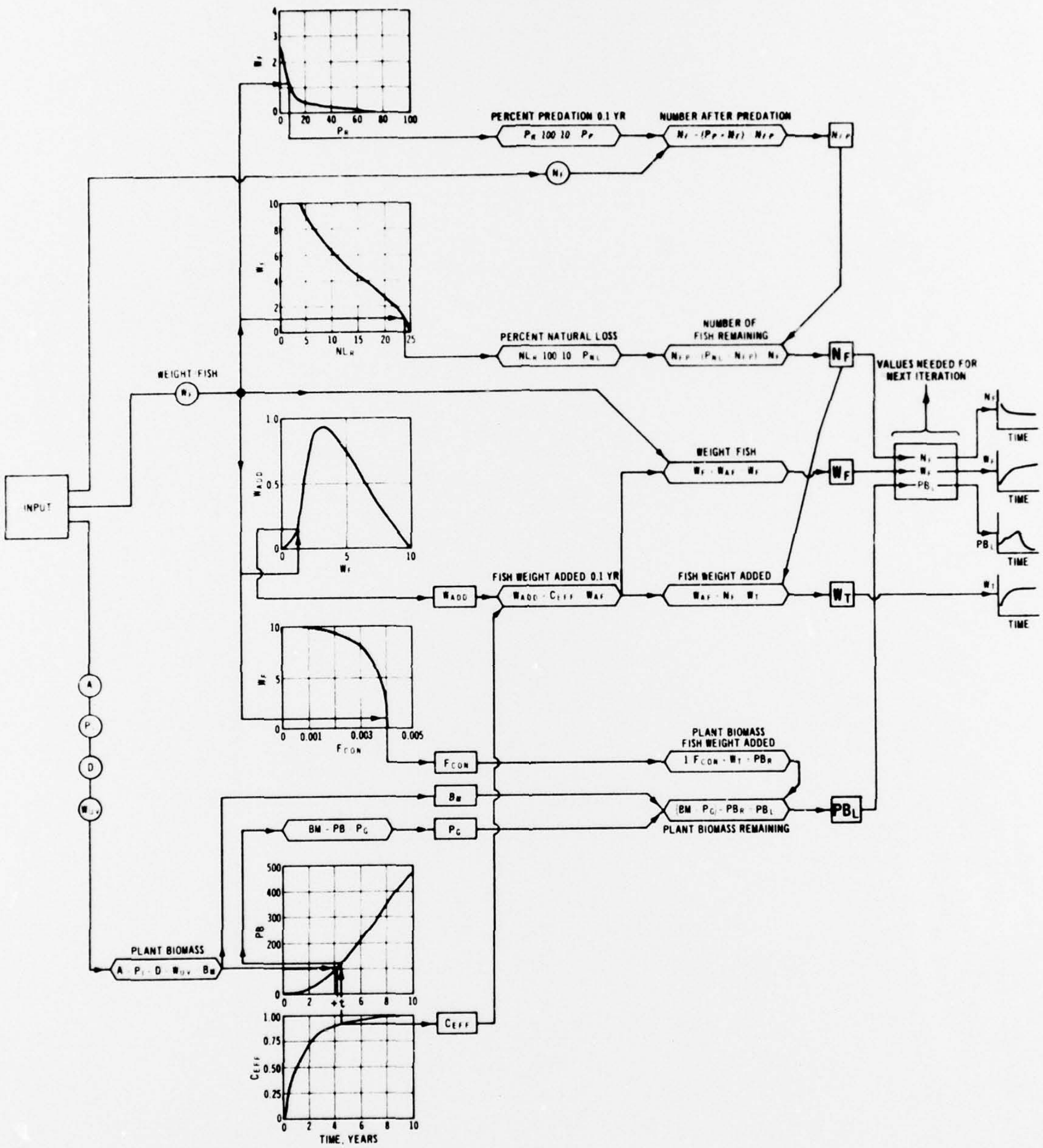

Figure 8. Flow diagram of logic for the white amur stocking rate model

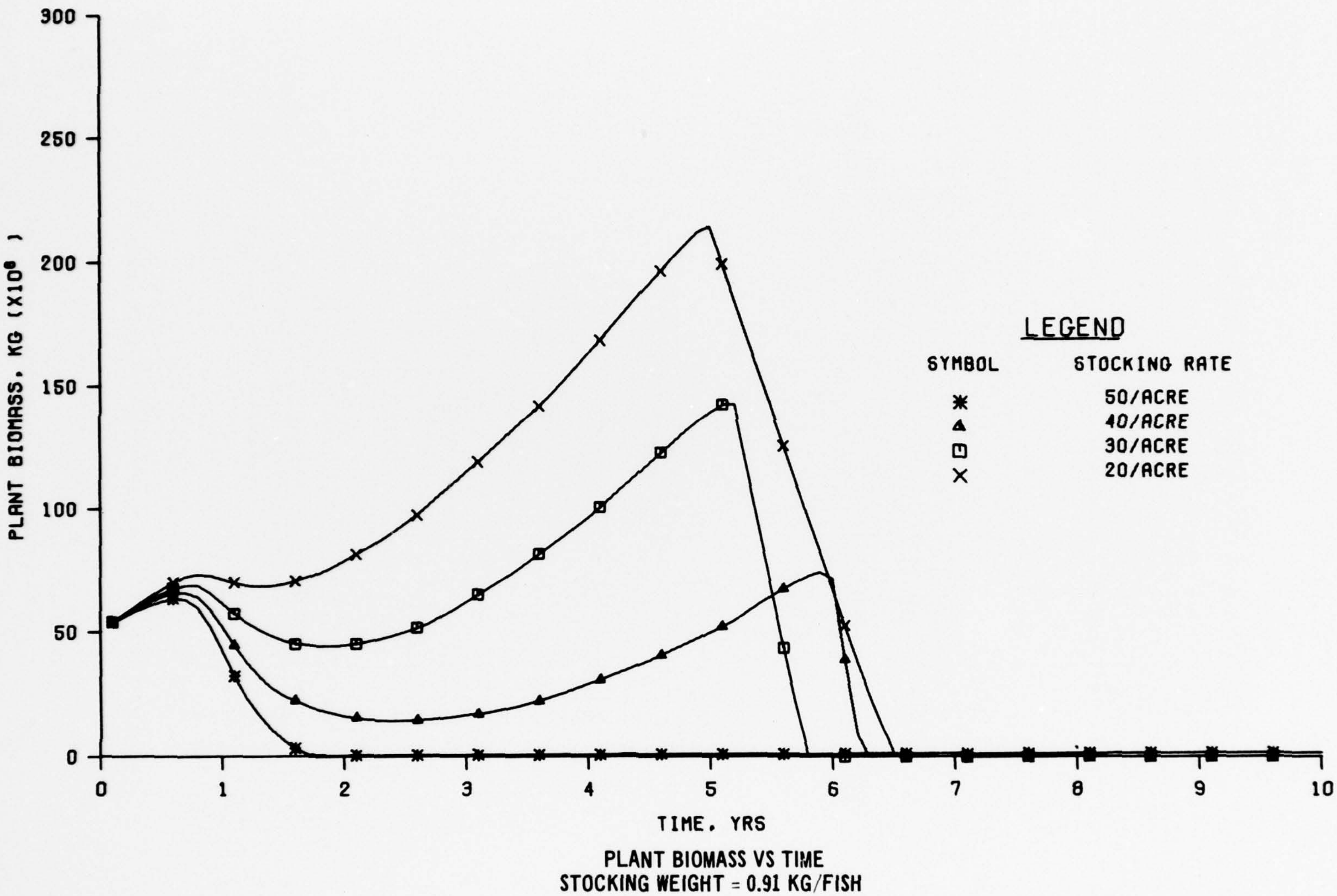

Figure 9. Graphic display of data computed by the stocking rate model

HARVESTER RECORD

DATE
STARTING TIME
ENDING TIME
LOCATION
LOAD NO.
TIME TO HARVEST LOAD (MIN: SEC)
DISTANCE TRAVELED TO HARVEST LOAD (FT)
TRANSPORTER HOOK-UP (HRS-CLOCK)
TRANSPORTER NO.
TIME TO TRANSFER LOAD (MIN: SEC)
TRANSPORTER UNHOOK (HRS-CLOCK)
RESUME HARVEST (HRS-CLOCK)

Figure 10. Data parameters related to the mechanical harvester segment of the Aqua-Trio system

control that is a time-dependent operation, and there are numerous parameters that reflect this fact. Shown in Figure 10 is a set of parameters related to the harvester segment of this operation, and there are similar sets for the transporter and truck, revealing those parameters pertinent to each mechanism. From the collection of data, each load can be traced from pickup by the harvester to deposit at the disposal site by the truck, and this information can be displayed as tables or charts, which can then be compared and analyzed. From these comparisons may come indications for improved operation or suggestions for modification to the harvesting scheme.

CONCLUDING REMARKS

These four efforts exemplify the great diversity that is a reality in the data management systems required in aquatic plant control research. Each involves tremendous effort and time and the participation of a large number of people. Although the individual characteristics require specific planning, design, and adaptation, there are four criteria prerequisite to achieving success that are common to all of them:

a. *Realization* and understanding of the importance of an effective system.

b. *Coordination* of all phases of development and use of the system.

c. *Appreciation* of each member of the team and its contribution to the overall objective.

d. *Cooperation* of all concerned.

SUMMARY COMMENTS

by

W. G. Shockley*

The meeting this year involved representatives from more Corps districts than we have had in the past. We have also heard and seen a wider spectrum of problems with aquatic weeds. This type of communication is what we hope to establish through these meetings; it helps us in the research area to determine which way our research should go in order to be more responsive to needs in the field.

One thing has been very apparent in the presentations and that is that, except in a few isolated instances, current methods are not very effective in controlling aquatic weeds. The problem is very real and it is going to get worse before it gets better.

I wish to thank everyone for the papers that have been presented at this meeting, the lively discussions, and the genuine interest that everyone has shown in wanting to solve the problem. I especially want to thank Bill Rushing for all the effort that he expended in setting up this meeting; let's all give him a round of applause.

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* Supervisory Research General Engineer, Chief, Mobility and Environmental Systems Laboratory, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

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United States. Waterways Experiment Station, Vicksburg, Miss.

Proceedings, Research Planning Conference on the Aquatic Plant Control Program, 19-22 October 1976, Atlantic Beach, Fla. Vicksburg, Miss. : U. S. Waterways Experiment Station, 1977.

xx, 300 p. : ill. ; 27 cm. (Miscellaneous paper - U. S. Army Engineer Waterways Experiment Station ; A-77-3)

Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C.

Includes bibliographies.

1. Aquatic plant control -- Congresses. 2. Research planning -- Congresses. I. United States. Army. Corps of Engineers. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Miscellaneous paper ; A-77-3.
TA7.W34m no.A-77-3